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A STUDY OF THE RESISTANCE CHARACTERISTICS OF SHIPS WITH HIGH DISPLACEMENT-LENGTH RATIOS

By

Robert F. Desel
Lieutenant, U. S. Navy
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(1943)

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(1945)

Submitted to the Department of Naval Architecture

And Marine Engineering On 15 May 1952 In

Partial Fulfillment of the Requirements for the Degree of

Naval Engineer

at the

Massachusetts Institute of Technology

1952

Cambridge, Massachusetts
15 May 1952

Professor Joseph S. Newell
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Sir:

In accordance with the requirements for the Degree of Naval Engineer, we submit herewith a thesis entitled, "A Study of the Resistance Characteristics of Ships with High Displacement-Length Ratios".

Respectfully,

Robert F. Desel
Lieutenant
U. S. Navy

John T. Collins
Lieutenant
U. S. Navy

A STUDY OF THE RESISTANCE CHARACTERISTICS OF SHIPS WITH HIGH DISPLACEMENT-LENGTH RATIOS

By

Robert F. Desel and John T. Collins

Submitted to the Department of Naval Architecture and Marine Engineering on 15 May 1952 in partial fulfillment of the requirements for the degree of Naval Engineer.

ABSTRACT

The authors present a series of contours for estimating residual resistance coefficients of ships whose displacement-length ratios are above those considered in Taylor's Standard Series. These contours cover a range of displacement-length ratios from 280 to 560, volume-length ratios from 8 to 16, and longitudinal prismatic coefficients from .58 to .70. In addition, a curve is provided for estimating wetted surface coefficients of these ships.

The data for this study were taken from 44 ship model tests that have been conducted at the David W. Taylor Model Basin over a period of years. These models in no way form a systematic series. Their hull forms are related only to the extent provided by over-all coefficients such as the displacement-length ratio, prismatic coefficient and beam-draft ratio.

The residual resistance coefficients for each model were calculated from the original test data using the Schoenherr friction formulation. These coefficients were used to determine average contours of volume-length coefficient on coordinates of prismatic coefficient and residual resistance coefficient at various Froude number values.

It should be emphasized that the resulting contours represent an average of the data from the 44 ship models studied. No particular model conforms exactly to the contours. To further stress this point, the calculated model data are plotted with the contours.

The contours as determined in this study indicate an optimum with regard to residual resistance coefficient at a prismatic coefficient of about .58. At this value of prismatic coefficient, the variation of residual resistance with prismatic coefficient is very slight. The contours also indicate that the variation of residual resistance coefficient with volume-length ratio at the optimum prismatic value is considerably less than at higher values of prismatic coefficient.

It is believed that the results of the study will be of value to designers in selecting hull form coefficients and for estimating the resistance of new designs. However, the data must be used with discretion, bearing in mind that it is an average of individual ships whose variations of resistance with details of design have not been completely evaluated.

The fact that definite trends in the resistance characteristics of the ships studied are evident indicates that it would be highly desirable to conduct a standard series type investigation in the region of high displacement-length ratios.

Thesis Supervisor: Prof. M. A. Abkowitz
Assistant Professor of Naval Architecture

ACKNOWLEDGMENTS

The authors of this thesis are indebted to many people for the encouragement and assistance rendered in the course of the study. They are particularly indebted to Dr. F. H. Todd of the David Taylor Model Basin for suggesting the work, and for his continuing advice and encouragement. They wish to express their gratitude to Captain H. E. Saunders, U. S. N. of the Bureau of Ships for his interest and advice. They are grateful to the Staff of the David Taylor Model Basin whose endeavours greatly facilitated the work. They acknowledge with special thanks, the assistance rendered by their thesis supervisor, Professor M. A. Abkowitz.

TABLE OF CONTENTS

I. NOMENCLATURE

Displacement-Length Ratio $\frac{\Delta}{(L/100)^3}$	Displacement in tons of salt water at 59° F divided by the cube of one percent of the length in feet
Volume-Length Ratio $\frac{\nabla}{(.1L)^3}$	Volume of displacement divided by the cube of ten percent of the length (nondimensional)
Residual Resistance Coefficient $C_R = \frac{R_R}{1/2\,\rho\, SV^2}$	Residual resistance divided by the product of one half, the mass density of water, wetted surface and velocity squared (nondimensional)
Longitudinal Prismatic Coefficient $C_p = \frac{\nabla}{A_x L}$	Volume of displacement divided by the product of the midship section area and the length (nondimensional)
Beam-Draft Ratio $\frac{B}{H}$	The ratio of beam to draft (nondimensional)
Block Coefficient $C_b = \frac{\nabla}{LBH}$	Volume of displacement divided by the product of length, beam, and draft (nondimensional)
Froude Number $V/\sqrt{gL}$	Velocity divided by the square root of the product of length and the acceleration of gravity (nondimensional)
Wetted Surface Coefficient $C_{SW} = S/\sqrt{\nabla L}$	Wetted surface divided by the square root of the product of volume of displacement and length

II. INTRODUCTION

There is a great lack of published data on the resistance characteristics of ships with high displacement-length ratios. This study is presented in an effort to provide some guides in a relatively unmarked area of hull design.

At present designers of ships with high displacement-length ratios rely primarily on their individual experience for the selection of suitable form parameters for new designs. Estimates of the resistance characteristics of new designs must be made almost entirely by comparisons with the relatively few ships of this type that fall within the designer's experience, or from individual model tests. The evaluation of the merits of any design are difficult because of the lack of any standard of comparison, such as Taylor's Standard Series provides at lower displacement-length ratios (below 250).

The first step in filling this void of information on high displacement-length ratio ships was taken by the Japanese after World War II. In the interests of the Japanese fishing industry, a standard series of model tests were conducted. The parent form for this series was a fishing vessel of the Tuna and Bonita Clipper type. The results of these experiments were published in 1950 and have come to be known as the "Takagi Series" in this country. The prototype for this series, however, is a very special type of vessel and can hardly be considered as representing high displacement-length ratio ships in general. The application of these results is, therefore, somewhat limited.

Even though there has been a lack of systematic data on the ships with high displacement-length ratios, there has been an accumulation of what might be called "scattered data" on this type of ship over the years. This data is the result of individual model experiments conducted at the David Taylor Model Basin and at the United States Experimental Model Basin over the past thirty years.

It is the purpose of this study to assemble and systematize, as far as possible, the accumulation of "scattered data" on ships with high displacement-length ratios.

III. PROCEDURE

The models to be used in this study were selected primarily on the basis that their displacement-length ratios were above 250. In order to eliminate any ships of peculiar form and to have the fullness as indicated by the high displacement-length ratio, represent a general fullness rather than just a fullness of beam, the selection was further restricted to models whose beam-draft ratio values were between two and three. The examination of the lines of the selected ships confirmed the logic of this choice in that they were all of generally ship-shape form. This selection yielded 44 models.

The original test data for each of the 44 models were assembled and these data were used to calculate values of residual resistance coefficient at various Froude numbers. The Schoenherr friction formulation was used throughout this work. The length of model used to compute Reynolds and Froude numbers was taken in each case as the actual water line length at the displacement of the test. This work provided sufficient information for plotting residual resistance versus Froude number curves for each model.

The residual resistance coefficient was selected as the basic resistance parameter. This choice was based on several factors:

1. It is a generally accepted parameter in this country.
2. Ships of the high displacement-length type are relatively short in comparison to their speeds and are, therefore, operating in ranges of Froude number where wave making resistance is of primary importance.

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1. It is a generally accepted parameter in this country.
2. Ships of the high displacement-length type are relatively short in comparison to their speeds and are, therefore, operating in ranges of Froude number where wave making resistance is of primary importance.

3. The residual resistance coefficient offers a satisfactory spread of values to differentiate resistance characteristics among these models.

4. It has a nondimensional form.

Froude number was selected as the speed parameter because of its nondimensional form. The parameters that were selected to define the hull form were the volume-length ratio and the longitudinal prismatic coefficient. These parameters were selected primarily because they gave the most favorable orientation of the resistance data with respect to hull form. Several other hull form parameters were considered, including length-beam ratio, beam-draft ratio, vertical prismatic coefficient, waterplane coefficient, and midshipsection coefficient. None of these, however, provided a good orientation among the models. It is not presumed that the selected parameters are the best. Further study might produce parameters that would provide a better orientation of models. However, it is felt that the improvement on parameters representing hull form would involve such items as the position of the center of buoyancy, angle of entrance of the load waterline, or entrance prismatic coefficient. These values could not be included in this study because they were not available for most of the models.

Using the selected parameters, contours of constant displacement-length ratio were faired on coordinates of prismatic coefficient and residual resistance coefficient at various Froude numbers. In fairing these contours the controlling factor was that they represent a good average of the available data. The averaging to arrive at these

contours was accomplished by eye. These contours were then cross-faired against constant prismatic coefficient, and constant residual resistance coefficient.

In addition a wetted surface coefficient was calculated for each model based on the square root of the volume-length product. This coefficient was plotted against midship section coefficient. An average curve was drawn through these points. This curve can be used to estimate the wetted surface coefficients of similar vessels.

IV. RESULTS

A. Contours of volume-length ratio on coordinates of longitudinal prismatic coefficient versus residual resistance coefficient at various Froude numbers.

B. Curve of average wetted surface coefficient versus midship section coefficient.

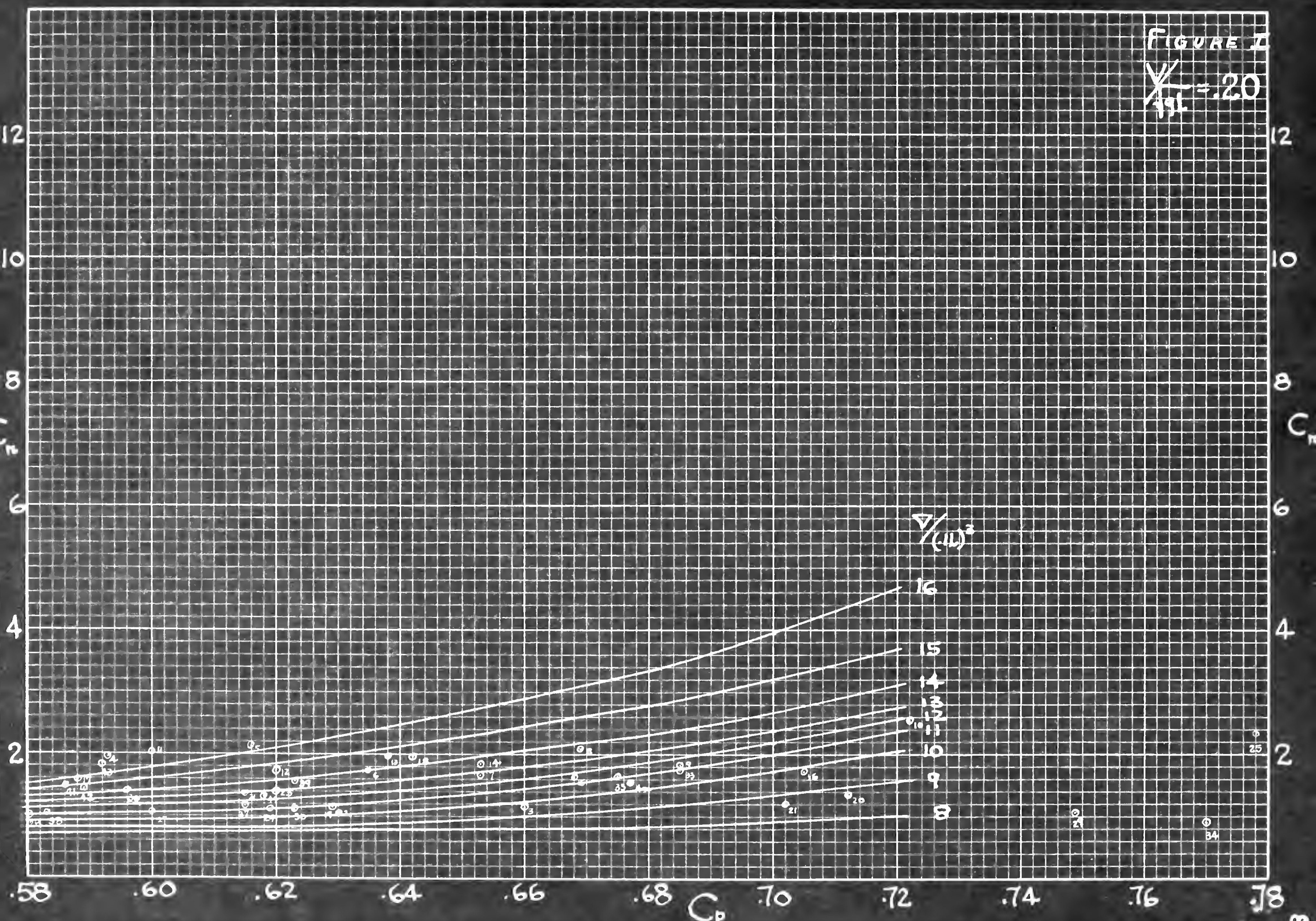

FIGURE I
V/√gL = .20
∇/(.1L)³
16
15
14
13
12
11
10
9
8
12
10
8
6
4
2
Cₙ
.58
.60
.62
.64
.66
.68
.70
.72
.74
.76
.78
Cₚ

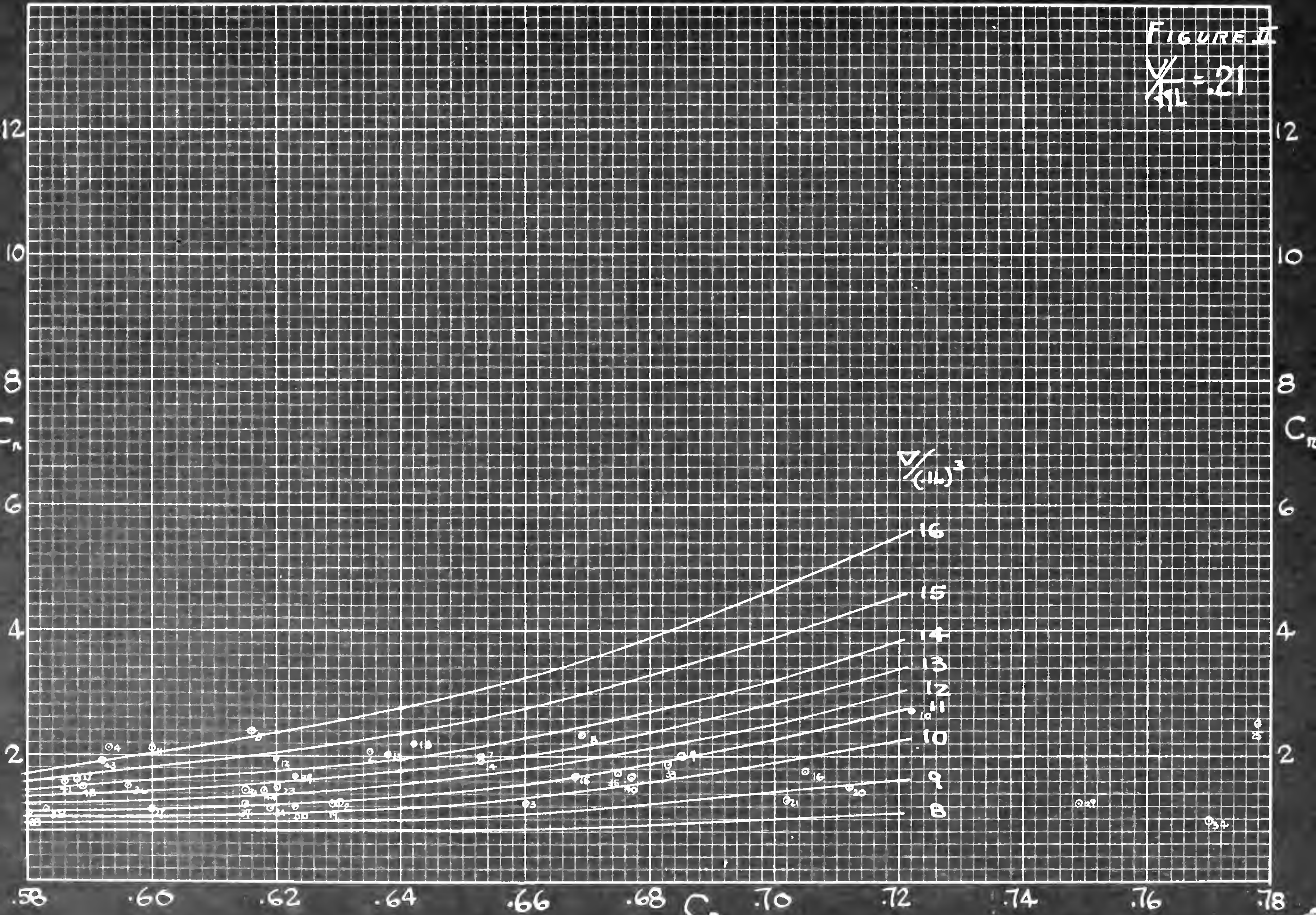

FIGURE II
$V/\sqrt{L} = .21$
$\nabla/(.1L)^3$
16
15
14
13
12
11
10
9
8
C_r
C_p
.58
.60
.62
.64
.66
.68
.70
.72
.74
.76
.78
2
4
6
8
10
12

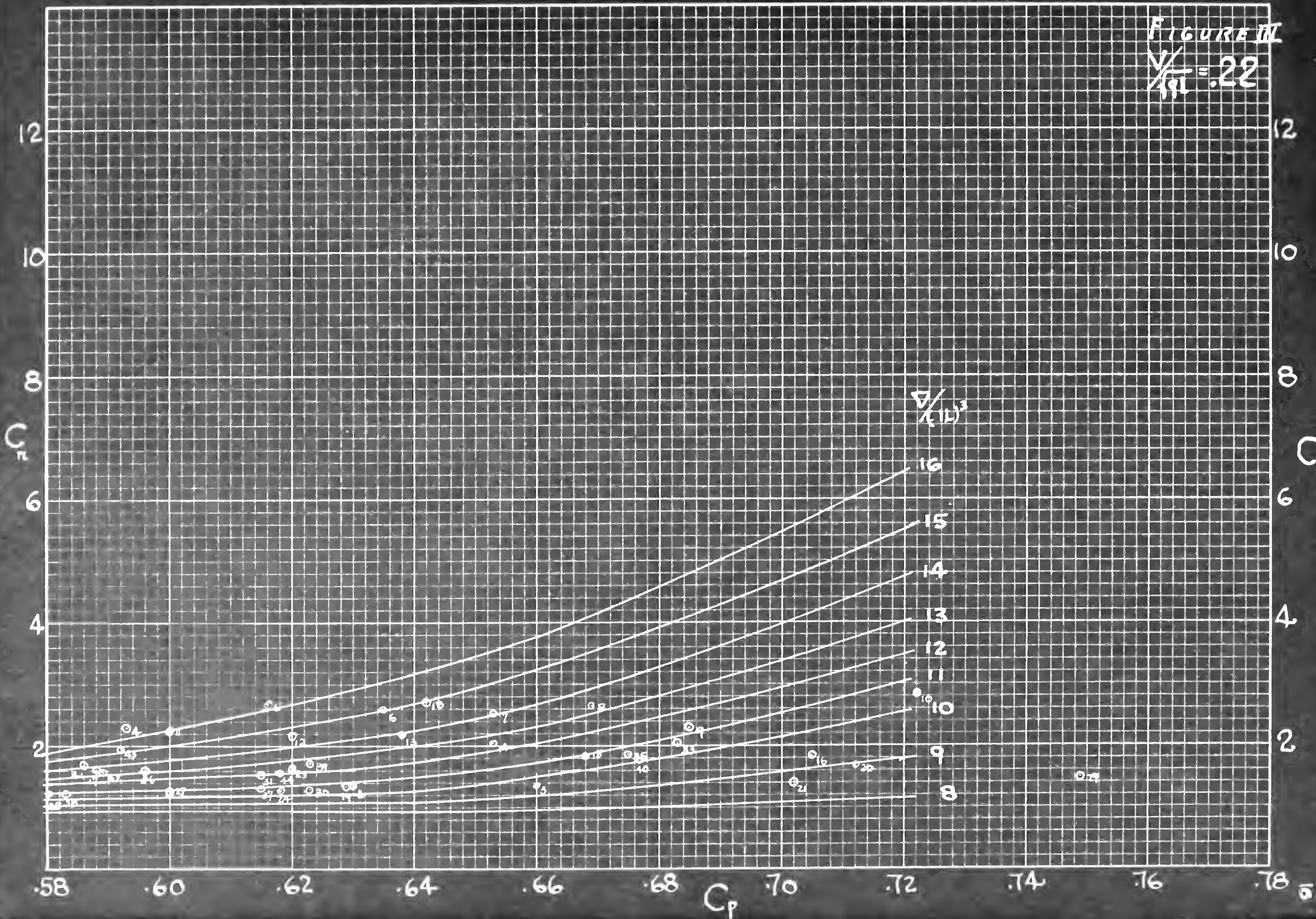

FIGURE IV
V/√gL = .22
∇/(.1L)³
16
15
14
13
12
11
10
9
8
Cr
Cp
.58
.60
.62
.64
.66
.68
.70
.72
.74
.76
.78
2
4
6
8
10
12

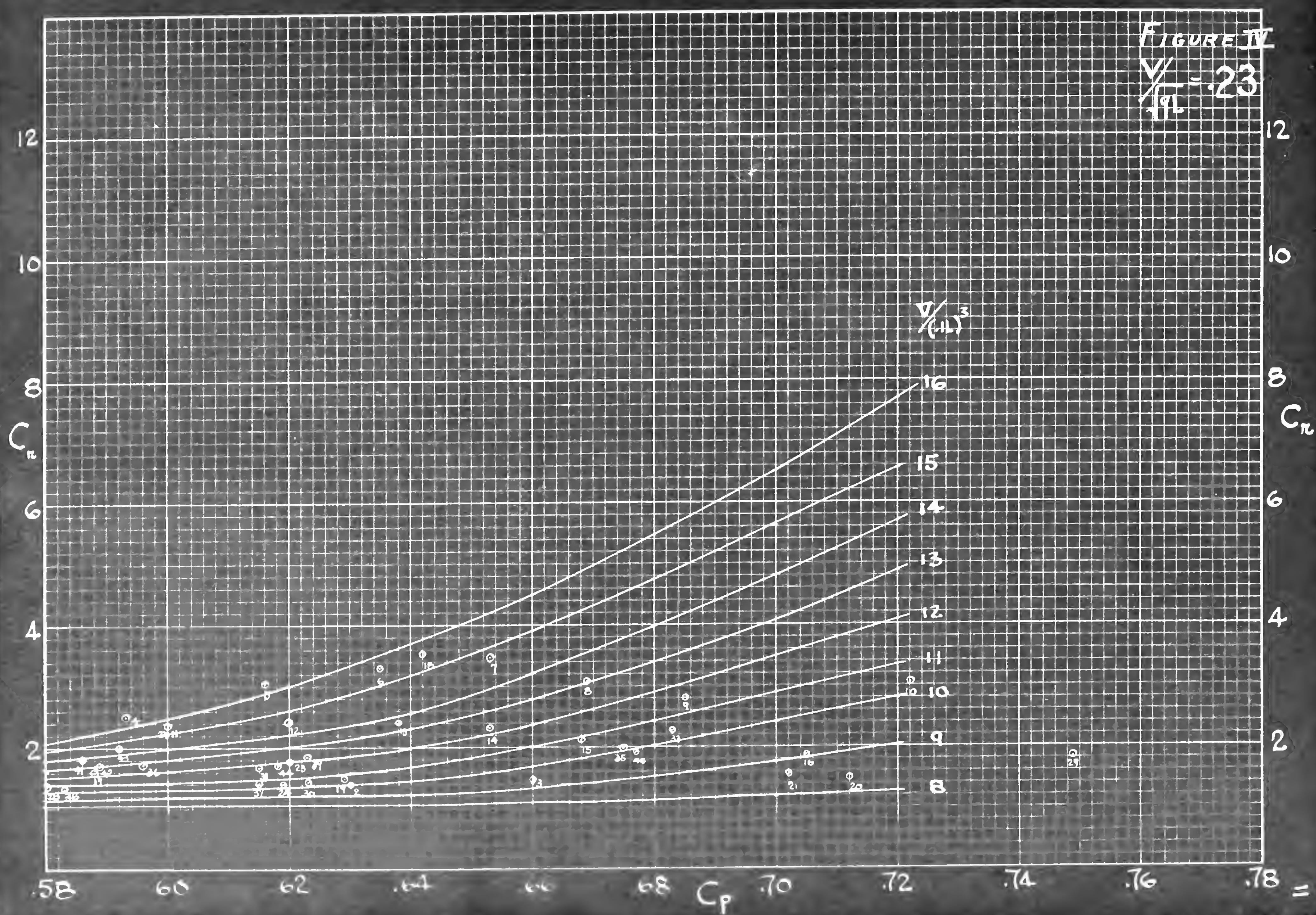

FIGURE IV
$V/\sqrt{gL} = .23$
$V/(.1L)^3$
16
15
14
13
12
11
10
9
8
C_R
C_P
.58
.60
.62
.64
.66
.68
.70
.72
.74
.76
.78
2
4
6
8
10
12

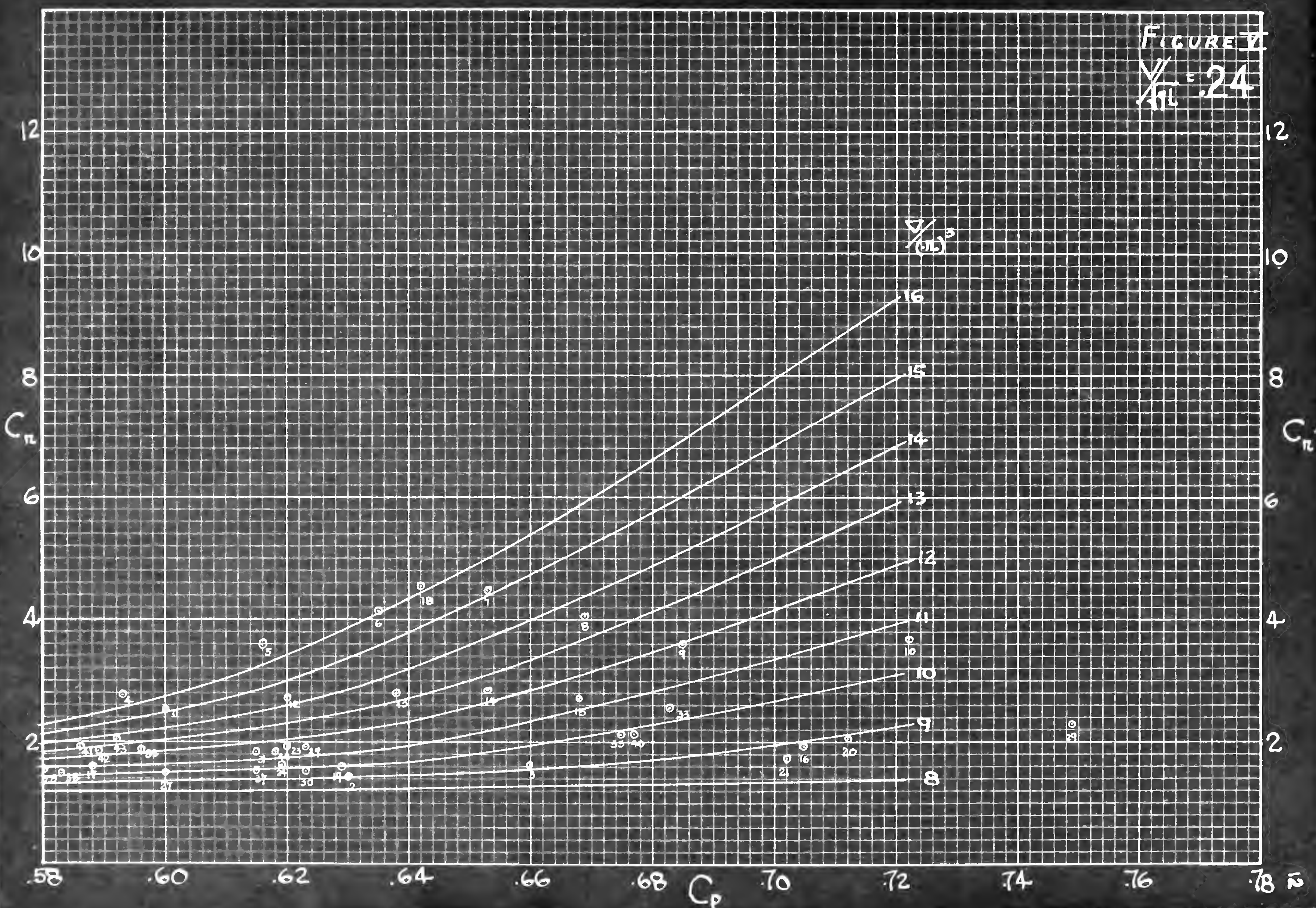
FIGURE V
$V/\sqrt{gL} = .24$
$\nabla/(.1L)^3$
16
15
14
13
12
11
10
9
8
C_π
C_p
.58
.60
.62
.64
.66
.68
.70
.72
.74
.76
.78
2
4
6
8
10
12

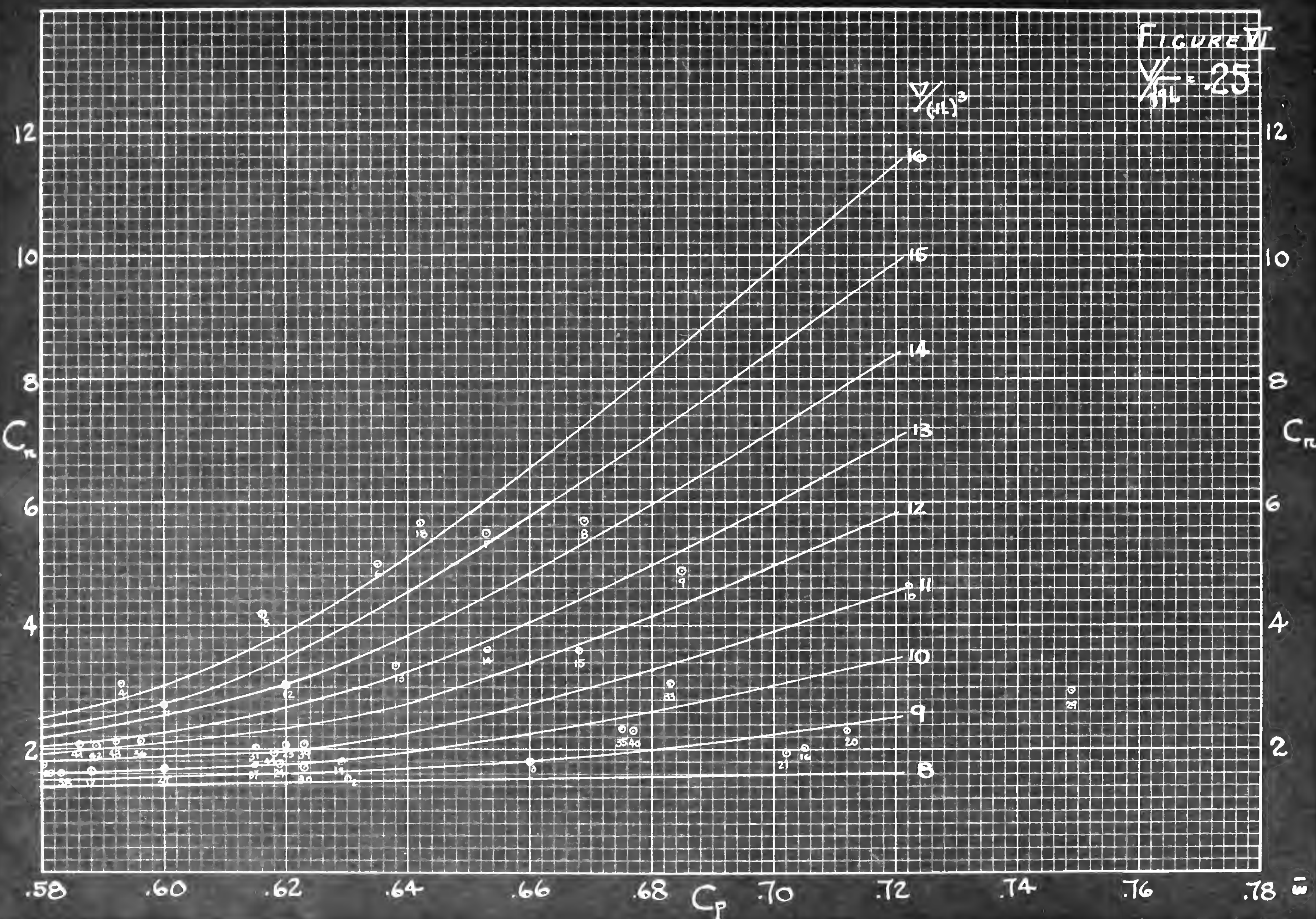

FIGURE VI
V/√(gL) = .25
V/(·1L)³
16
15
14
13
12
11
10
9
8
C_R
C_P
.58
.60
.62
.64
.66
.68
.70
.72
.74
.76
.78
2
4
6
8
10
12

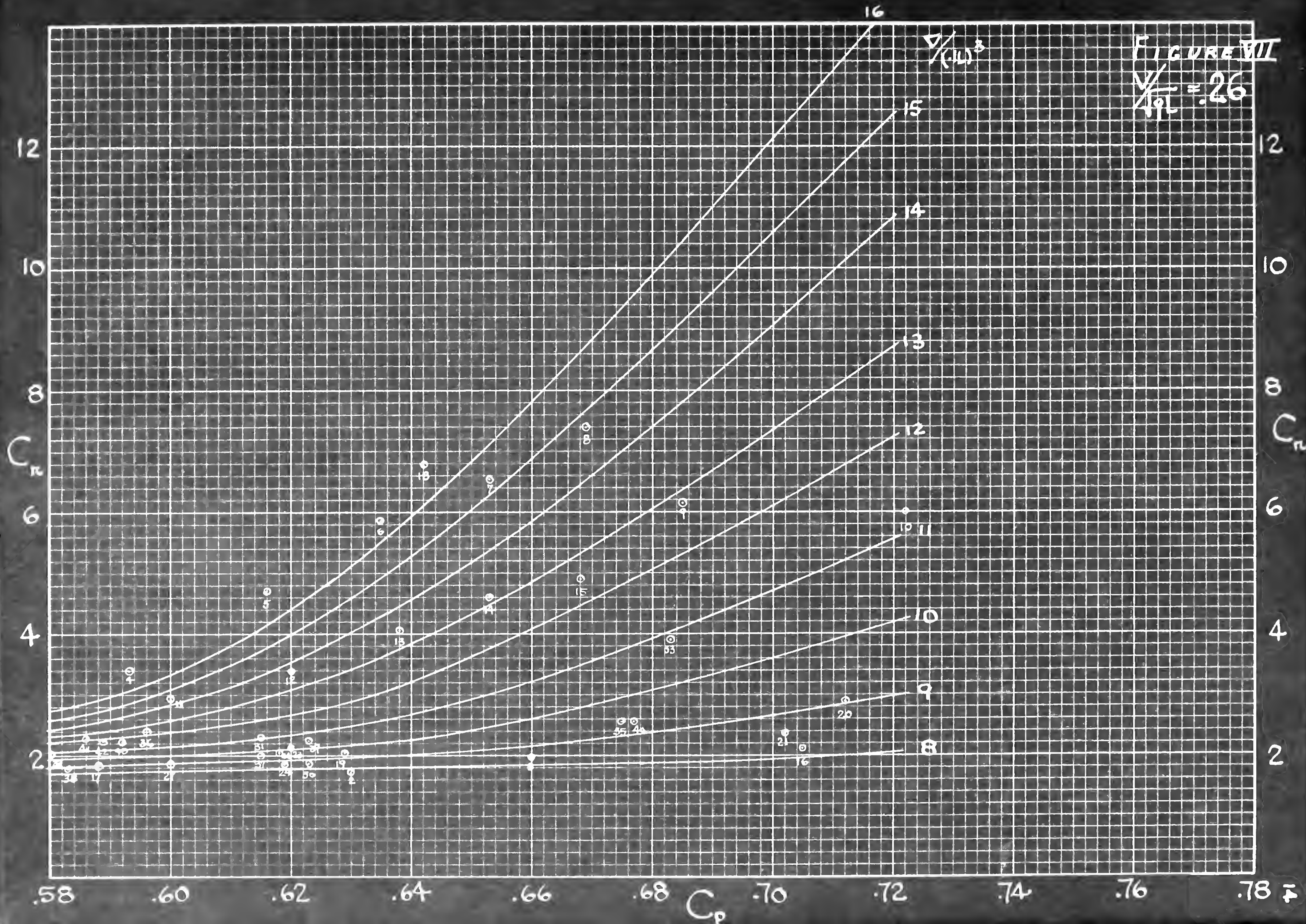
FIGURE VIII
$V/\sqrt{gL} = .26$
$\nabla/(.1L)^3$
16
15
14
13
12
11
10
9
8
C_R
C_p
.58 .60 .62 .64 .66 .68 .70 .72 .74 .76 .78
2 4 6 8 10 12
MADE IN U.S.A.

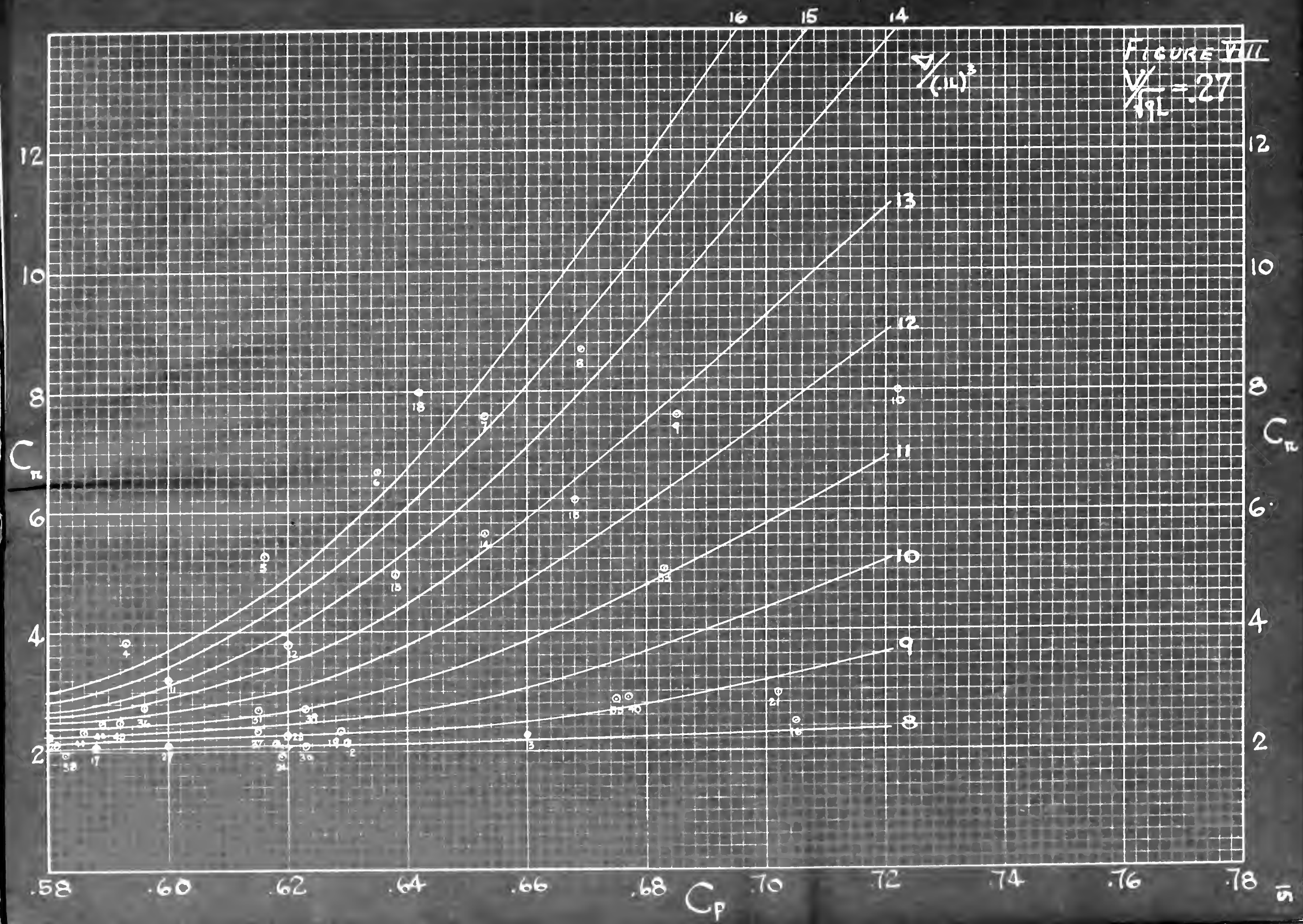

FIGURE VIII
$\frac{V}{\sqrt{gL}} = .27$
$\nabla/(.1L)^3$
16
15
14
13
12
11
10
9
8
C_π
C_p
.58
.60
.62
.64
.66
.68
.70
.72
.74
.76
.78
2
4
6
8
10
12

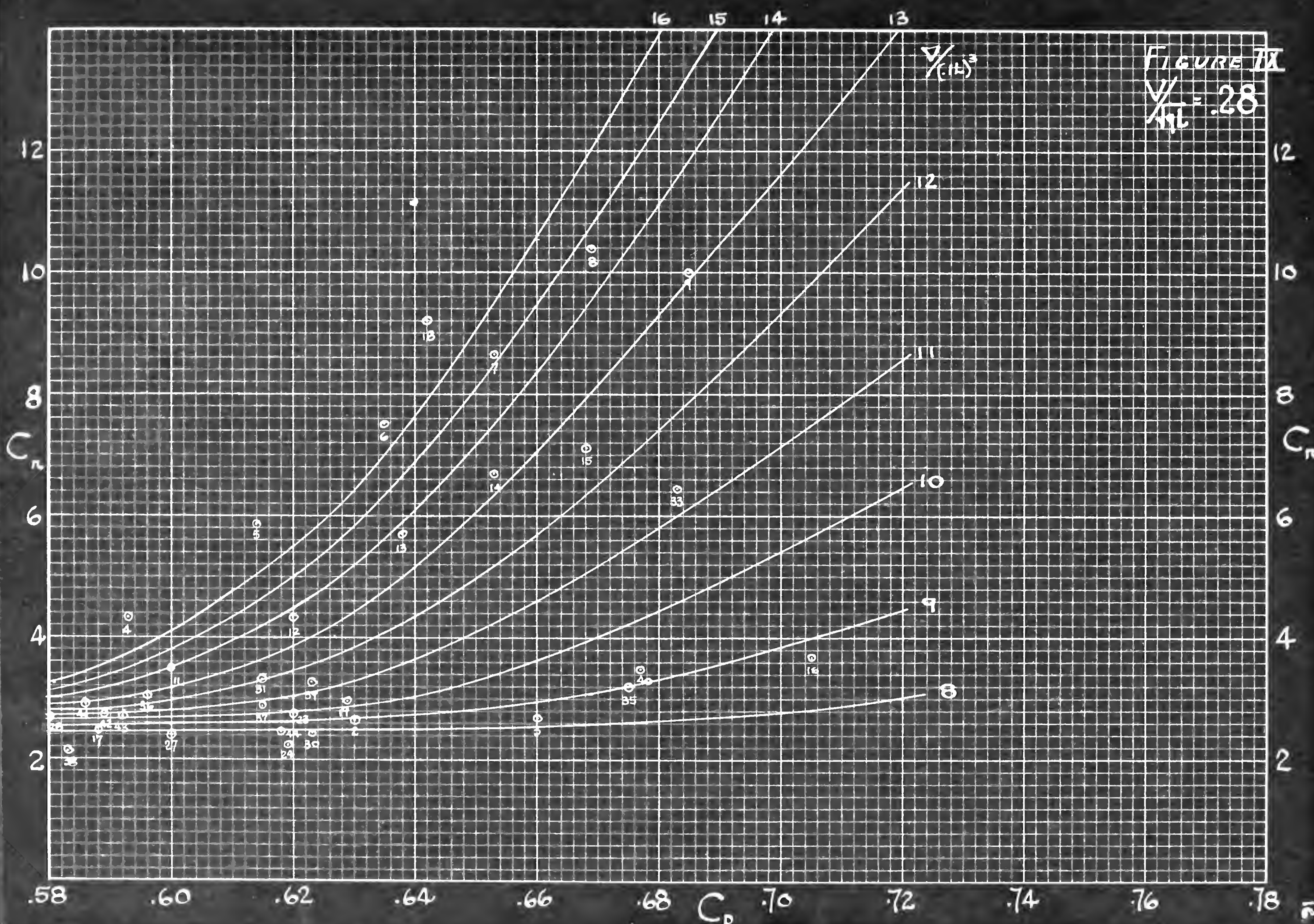
FIGURE IX
V/ΔL = .28
V/(.1L)³
16
15
14
13
12
11
10
9
8
Cn
Cp
.58
.60
.62
.64
.66
.68
.70
.72
.74
.76
.78
2
4
6
8
10
12

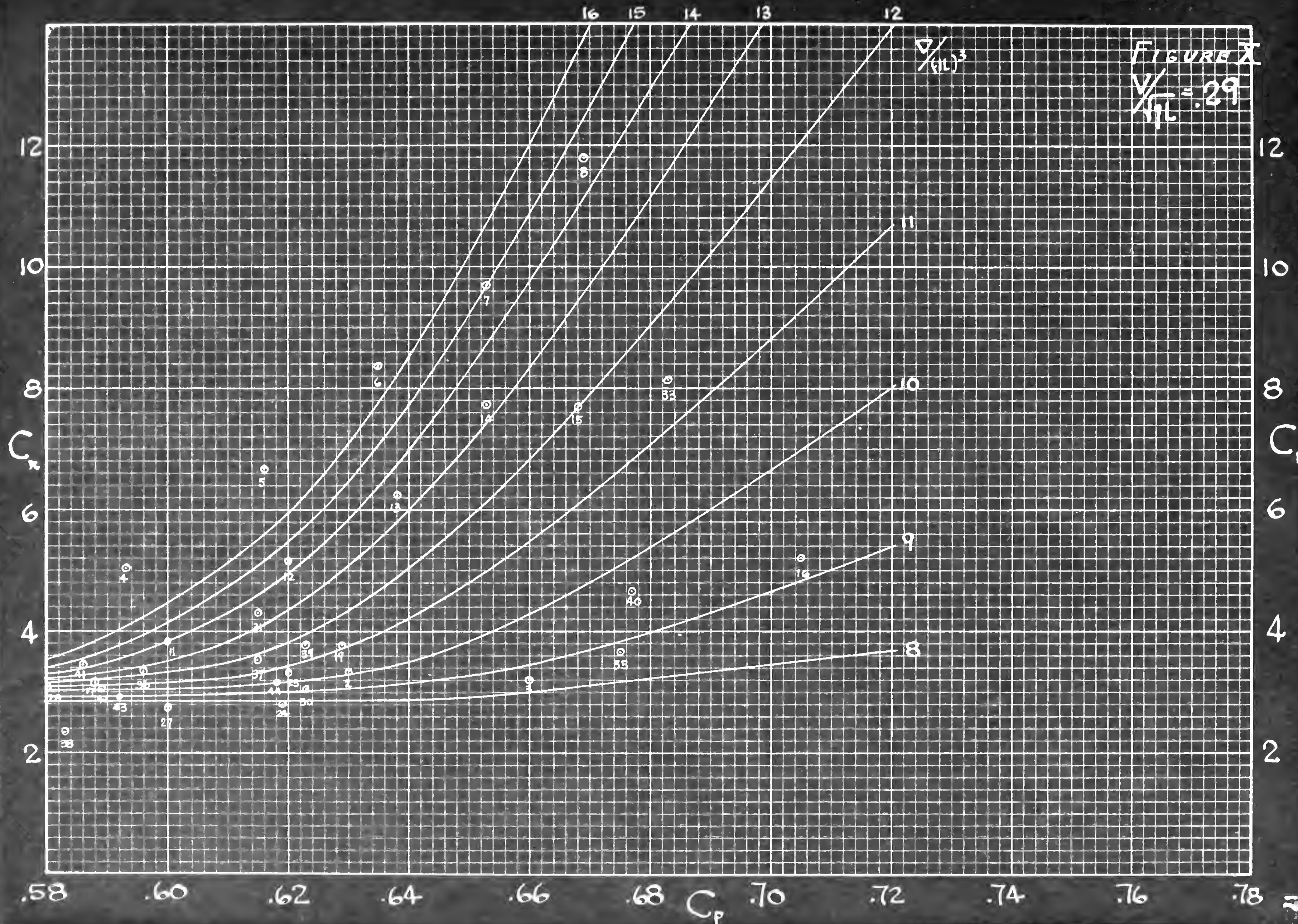

FIGURE X
V/√L = .29
∇/(.1L)³
16
15
14
13
12
11
10
9
8
.58
.60
.62
.64
.66
.68
.70
.72
.74
.76
.78
C_p
C_r
C_r
2
4
6
8
10
12

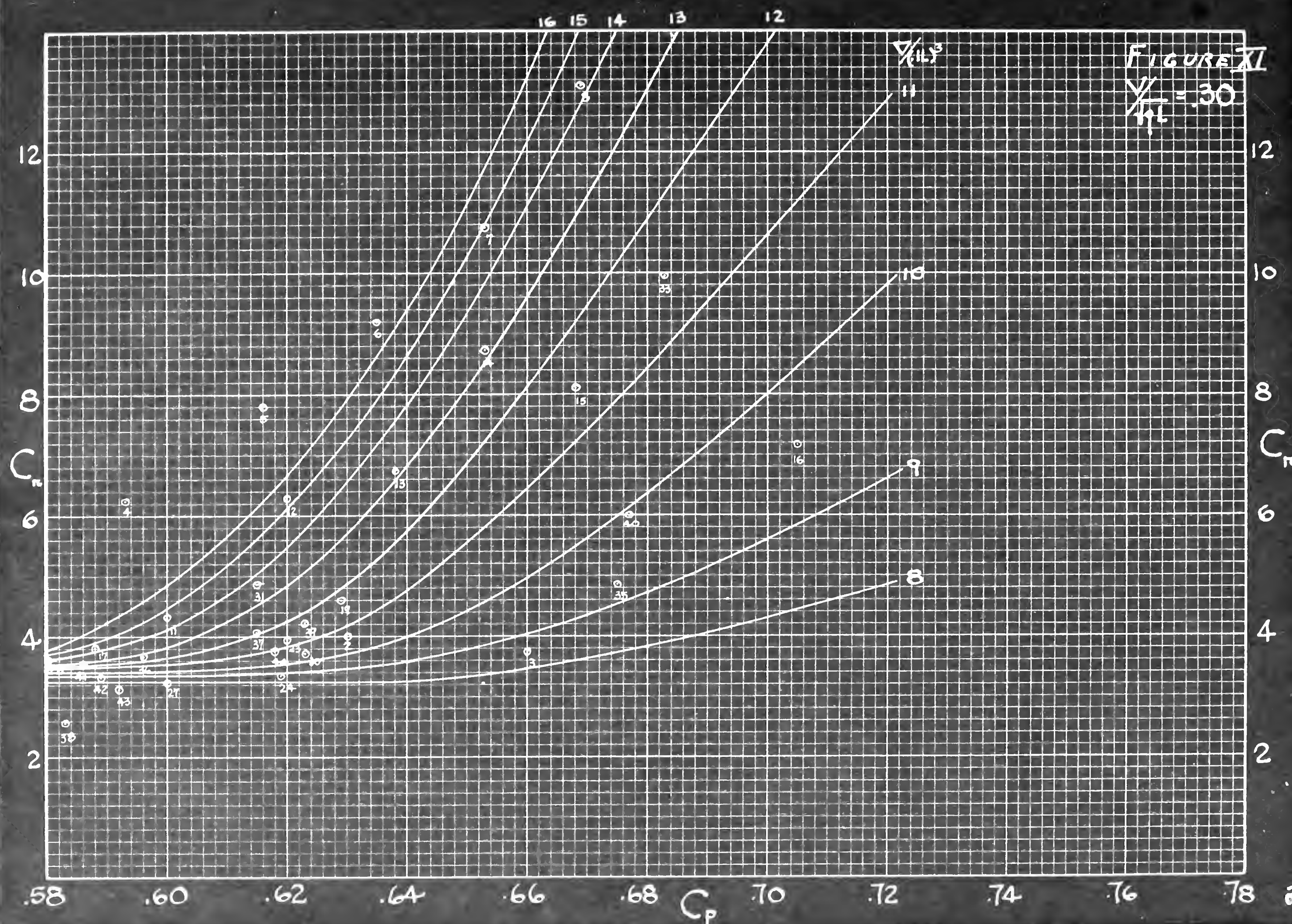

FIGURE XI
$\frac{V}{(\frac{1}{10}L)^3} = .30$
$\frac{\nabla}{(\frac{1}{10}L)^3}$
16
15
14
13
12
11
10
9
8
C_r
C_p
.58
.60
.62
.64
.66
.68
.70
.72
.74
.76
.78
2
4
6
8
10
12

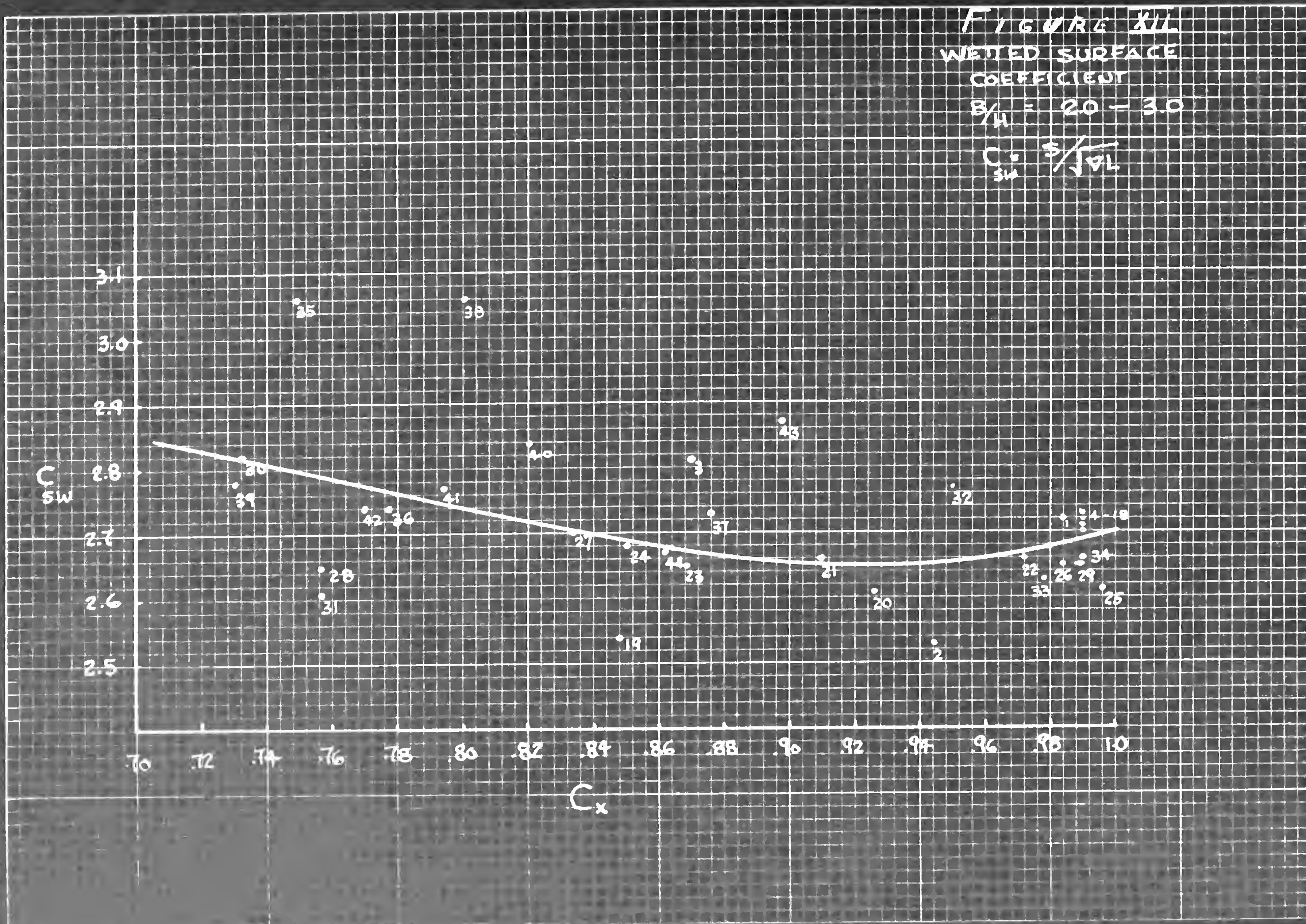
FIGURE XII
WETTED SURFACE COEFFICIENT
B/H = 2.0 – 3.0
$C_{SW} = S/\sqrt{\nabla L}$
C_{SW}
3.1
3.0
2.9
2.8
2.7
2.6
2.5
.70
.72
.74
.76
.78
.80
.82
.84
.86
.88
.90
.92
.94
.96
.98
1.0
C_x

V. DISCUSSION OF RESULTS

It must be emphasized that the contours resulting from this study represent an average of the data from the 44 ship models. No particular model will have the exact resistance characteristics predicted by the contours. While individual ship resistance curves tend to have humps and hollows in them, the averaging process used in determining the contours tended to eliminate these fluctuations, although they produced what is believed to be the initial portion of a hump at Froude numbers near .30.

In order to emphasize the scattering of data, and to allow for a reexamination of the contours, the actual data has been plotted with the contours.

The study that was involved in the selection of the hull form parameters to best represent the effect of form variation on the residual resistance coefficient, indicated that none of the overall form coefficients was entirely satisfactory. Various combinations of these parameters were tried without finding any better correlation. This fact fostered the belief that the details of design, such as the arrangement of skeg, rudders, and stem had considerable influence on the resistance. In addition, it is felt that better correlation might have been attained if it had been possible to include such items as the longitudinal position of the center of buoyancy, the angle of water line entrance, and the entrance prismatic coefficient in the parameters defining the hull form.

V. DISCUSSION OF RESULTS

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The authors compared the determined contours with a similar contour derived from Taylor's Standard Series at a volume-length ratio of 7.0. In general, there was good agreement both in shape and magnitude. At high Froude numbers, however, in the vicinity of .30, the Taylor contour tended to rise more sharply to higher values. This indicates that the Taylor contours provide a more pronounced hump in the resistance curve at Froude numbers in the vicinity of .30. The higher residual resistance coefficient values, as indicated by the Taylor contours, was not borne out by the model evidence.

A similar comparison was made between the derived contours and contours taken from the "Takagi" series. In this case, the derived contours showed a much wider variation of the residual resistance coefficient with volume-length ratio at all Froude numbers and prismatic coefficients. The best agreement occurred at the low Froude numbers. At the lowest prismatic coefficients (.58), the Takagi values were slightly higher than the determined contours for all volume-length ratio values. At the higher prismatic coefficients the Takagi values for high volume-length ratios were considerably lower, and for low volume-length ratios were slightly higher than the determined contours throughout the range of Froude number values.

The crossover area where the derived contours and the Takagi contours are in good agreement were as follows:

Cp.	Crossover $\nabla/(.1L)^3$
.70	9.5
.67	10.3
.64	12
.61	14

It is felt that the determined contours better represent the average of the models studied than does the Takagi series data. This is no doubt due to the specific type of ship that formed the prototype of the Takagi series.

A third comparison was made. This comparison is between the originally calculated residual resistance coefficient curves for each model and a similar curve taken from the derived contours. These curves will be found in the Appendix of this thesis. The results of this comparison were as follows:

Twenty-four of the predictions agreed quite well with the original curves. Of these 24, 14 could be classed as completely reliable predictions. Five were predicted too high and five were predicted too low. Of the remaining models, nine were predicted considerably higher and two considerably lower than the original data indicated. Nine other models had hull form parameters that did not fall within the range for which the contours were drawn, although they were used to aid in determining the contours.

It has been proposed in many quarters that a standard series be run in this country to obtain data on the resistance characteristics of ships in the higher ranges of displacement-length ratio.

This study indicates that the choice of a prototype for such a series might be difficult. The type of ship to be represented seems to have considerable bearing on the problem. For example, this study indicates a tendency for tugboat types to show somewhat lower resistance in general than the average contours, whereas other types such as merchant ship forms are generally more consistent with the derived contours. These tendencies are no doubt due to details of design not represented by the selected form parameters. To get one prototype which would yield data consistent with all types seems rather unlikely.

The optimum value of prismatic coefficient with respect to minimizing the residual resistance coefficient is indicated at about a prismatic coefficient of .58. In this vicinity at all Froude numbers, the variation of residual resistance with prismatic coefficient is rather small. In addition, the contours in the vicinity of the optimum prismatic coefficient indicate a less pronounced variation of the residual resistance coefficient with changes in volume-length ratio than at higher prismatic coefficients. This location for the optimum prismatic coefficient agrees well with what might be predicted from Taylor's Standard Series.

It is believed that this study can be of value and assistance to Naval Architects in selecting hull form parameters and in predicting the resistance characteristics of new designs in the high displacement-length ratio range. In addition, it can form a basis of comparison and reference. It is hoped that the presentation is

such that additional information and data can be added as new designs are tested, thus providing evidence for either verifying or modifying the presented contours.

VI. CONCLUSIONS

1. Average resistance characteristics of ships with displacement-length ratios above 250 and whose beam-draft ratios lie between 2 and 3 can be predicted by the contours presented.
2. The optimum value of longitudinal prismatic coefficient based on minimum residual resistance coefficient is about .58.
3. At the optimum value of longitudinal prismatic coefficient, the variation of residual resistance coefficient with displacement-length ratio is small.
4. The variation of residual resistance coefficient with displacement-length ratio increases with increase of longitudinal prismatic coefficient above the optimum.
5. The parameters used to define the model hull forms are not the only ones influencing the residual resistance characteristics of the ships. Therefore, any particular model may have resistance characteristics greatly different from those predicted by these curves solely from the fact that an important form parameter is not included in the identification of the vessel.
6. It is felt that the angle of entrance of the load waterline, and the longitudinal position of the center of buoyancy are the most significant parameters that were not available for this study.
7. It is possible to systematize "scattered data" on the resistance characteristics of ships. The results, while not as conclusive as could be derived from a standard series of model tests, do provide generalized trends which are of value.

VII. RECOMMENDATIONS

1. It is recommended that a standard series type investigation be carried out for ships of high displacement-length ratios using the data that has been presented here to aid in the selection of a prototype vessel or parent form.

2. It is recommended that the data as presented here be used as a starting point for further correlation and for comparison with new designs as they are tested. To a large extent, the value of this study lies in its use for further comparisons, correlations, and additions to the systematized collection of data with a view toward improving the contours presented.

3. The contours as presented should be used with discretion in predicting the residual resistance characteristics of new designs, bearing in mind the deviation of individual models from the average contours.

VIII. APPENDIX

Appendix (A)

Supplementary Introduction

The index of the models whose resistance data was used in this study is included, believing that it will be of value in any further analysis of the presented contours. It contains most of the hull form parameters that might be of use together with a brief description of the type of vessel and the Taylor Model Basin model number associated with the model.

Appendix (D) is a sample calculation sheet for calculating the residual resistance coefficients, Froude numbers, C and K values. This form was taken from the publication listed in the Bibliography as item [6] and Taylor Model Basin calculation form Number 71.

Appendix (E) contains the original model test data from which the residual resistance coefficient, Froude numbers, C and K values were calculated, together with the residual resistance coefficient curve, both as calculated from the original model test data and as determined from the contours for each model. Curves of C versus K are also included for each model, believing that they may be of value in judging the merits of particular ships.

Appendix (F) is the Bibliography of the thesis.

Appendix (B)

Symbols

L	Length — feet
B	Beam — feet
H	Draft — feet
Δ	Displacement-pounds or tons
∇	Volume of displacement - cubic feet
S	Wetted Surface - square feet
ρ	Mass density of water - pound $sec^2/feet^4$
ν	Kinematic Viscosity - ft^2/sec
V	Velocity — feet per second
V_k	Velocity — knots
Re	Reynolds number VL/ν (nondimensional)
$V/\sqrt{gL}$	Froude number (nondimensional)
R_T	Total Resistance — pounds
R_f	Frictional Resistance — pounds
R_R	Residual Resistance — pounds
C_T	Total Resistance Coefficient $R_T/\frac{1}{2}\rho SV^2$ (nondimensional)
C_f	Frictional Resistance Coefficient $R_f/\frac{1}{2}\rho SV^2$ (nondimensional)
C_R	Residual Resistance Coefficient $R_R/\frac{1}{2}\rho SV^2$ (nondimensional)

© 400 foot ship $= \dfrac{427.1}{\Delta'^{2/3}\ V_k'^{3}} \cdot \dfrac{1/2\,\rho\, S V_k'^{3} C_T\,(1.689)^3}{550} =$

$$\frac{427.1\ EHP_T}{\Delta'^{2/3}\ V_k'^{3}}$$

K $\quad$ 400 foot ship $= \dfrac{.5834\ V_K'}{\Delta'^{1/6}}$

EHP_T $\quad$ Total Effective Horsepower — horsepower

$\nabla/(.1L)^3$ $\quad$ Volume length ratio $\quad$ (nondimensional)

$\Delta/(L/100)^3$ $\quad$ Displacement-length ratio $\quad$ Tons (saltwater 59°F)/ft³

C_p $\quad$ Longitudinal prismatic coefficient ∇/Midship section area · L (nondimensional)

C_b $\quad$ Block Coefficient ∇/LBH

C_x $\quad$ Midship Section Coefficient $\dfrac{\text{Midship Section Area}}{BH}$ (nondimensional)

C_{PV} $\quad$ Vertical Prismatic Coefficient ∇/Waterplane Area × H

C_W $\quad$ Waterplane Coefficient $\dfrac{\text{Waterplane Area}}{L \times B}$

C_{SW} $\quad$ Wetted Surface Coefficient $S/\sqrt{\nabla L}$

' $\quad$ Prime refers to 400 foot ship

Appendix (C)

Index of Models

TABLE I
INDEX OF MODELS

SERIAL NO.	MODEL No.	$\Delta/(L/100)^3$	$\nabla/(.1L)^3$	C_p	C_x	C_b	C_{pv}	C_w	C_{sw}	L/B	B/H	REMARKS.
1	2433	305.8	10.70	.800	.984	.787	.890	.890	2.72	5.58	2.36	SINGLE SCREW SUCTION DREDGE
2	2646	258.0	8.98	.632	.945	.604	.838	.721	2.53	5.09	2.59	SINGLE SCREW ICE BREAKER
3	2834	261.0	9.10	.659	.871	.573	.747	.768	2.82	4.54	3.00	SURVEY SHIP
4	3064	549.0	19.20	.593	.990	.588			2.72	3.50	2.50	SERIES 53 (4-1-0)
5	3064	511.0	17.90	.616	.990	.611			2.72	3.70	2.50	SERIES 53 (4-1-.5)
6	3064	475.0	16.65	.635	.990	.631			2.72	3.90	2.50	SERIES 53 (4-1-1)
7	3064	440.0	15.40	.653	.990	.659			2.70	4.10	2.50	SERIES 53 (4-1-1.5)
8	3064	411.0	14.37	.669	.990	.664			2.71	4.30	2.50	SERIES 53 (4-1-2)
9	3064	382.0	13.38	.685	.990	.678			2.71	4.50	2.50	SERIES 53 (4-1-2.5)
10	3064	315.0	11.08	.722	.990	.716			2.71	5.10	2.50	SERIES 53 (4-1-4)
11	3065	424.0	14.82	.600	.990	.595			2.70	4.00	2.50	SERIES 53 (5-1-0)
12	3065	397.0	13.90	.620	.990	.614			2.70	4.20	2.50	SERIES 53 (5-1-.5)
13	3065	374.0	13.10	.638	.990	.632			2.70	4.40	2.50	SERIES 53 (5-1-1)
14	3065	350.0	12.25	.653	.990	.647			2.70	4.60	2.50	SERIES 53 (5-1-1.5)
15	3065	327.0	11.44	.668	.990	.661			2.73	4.80	2.50	SERIES 53 (5-1-2)
16	3065	274.0	9.57	.705	.990	.700			2.70	5.40	2.50	SERIES 53 (5-1-3.5)
17	3068	277.0	9.69	.588	.990	.584			2.72	4.90	2.50	SERIES 53 (2-2-1)
18	3070	344.0	12.06	.642	.990	.637			2.71	4.60	2.50	SERIES 53 (4-2-1.5)
19	3102	293.0	10.25	.629	.848	.534			2.54	4.18	2.99	COAST GUARD CUTTER.
20	3121 A	316.0	11.08	.712	.926	.660			2.61	5.34	2.09	FREIGHT PASSENGER SHIP.
21	3121 B	258.0	9.01	.702	.910	.639			2.64	5.22	2.61	FREIGHT PASSENGER SHIP.
22	3132	281.0	9.82	.807	.972	.784	.880	.920	2.66	5.99	2.22	DREDGE
23	3138 A	380.0	13.30	.620	.868	.540	.700	.770	2.65	4.29	2.21	HARBOR TUG.
24	3138 B	345.0	12.10	.619	.850	.524			2.68	4.15	2.54	HARBOR TUG.

INDEX OF MODELS

SERIAL No	MODEL No	$\Delta/(\frac{L}{100})^3$	$\nabla/(.1L)^3$	C_P	C_X	C_b	C_{PV}	C_W	C_{SW}	L/B	B/H	REMARKS
25	3175	275.5	9.63	.778	.996	.774	.892	.865	2.61	5.36	2.80	HOPPER DREDGE
26	3472	272.0	9.65	.788	.984	.775	.919	.842	2.65	5.36	2.80	HOPPER DREDGE
27	3486	378.0	13.20	.600	.834	.498	.676	.737	2.70	4.18	2.15	TUG
28	3498	265.8	9.29	.586	.757	.438	.602	.726	2.69	4.24	2.63	HARBOR CUTTER
29	3685	246.6	8.62	.749	.989	.741	.908	.814	2.65	6.04	2.35	
30	3703	274.0	9.59	.623	.859	.535	.686	.779	2.82	4.80	2.42	TUG
31	3705	341.5	11.94	.615	.758	.467	.508	.725	2.61	4.06	2.38	COAST GUARD CUTTER
32	3714	259.0	9.05	.822	.950	.781			2.77		2.12	CONCRETE TANKER BARGE.
33	3725	254.5	8.90	.683	.978	.668	.901	.739	2.63	5.30	2.68	FUEL OIL BARGE.
34	3745	245.5	8.56	.770	.990	.762	.913	.832	2.66	6.58	2.06	CONCRETE BARGE.
35	3755	243.0	8.50	.675	.749	.505	.636	.793	3.06	4.66	2.72	COSTAL MINE SWEEP.
36	4085	285.5	10.00	.596	.757	.451	.622	.738	2.75	4.08	2.73	TUG
37	4086	350.0	12.23	.615	.876	.538	.711	.758	2.73	4.24	2.44	TUG
38	4087	434.0	15.17	.583	.801	.467	.626	.745	3.06	3.27	2.88	TUG
39	4088	481.5	16.89	.623	.873	.544	.701	.776	2.78	3.72	2.34	TUG
40	4090	294.0	10.30	.677	.821	.556	.717	.776	2.84	4.47	2.71	TUG
41	4091	347.0	12.15	.586	.794	.465	.648	.717	2.77	3.81	2.67	TUG
42	4093	393.0	13.75	.589	.770	.453	.611	.742	2.74	3.62	2.52	TUG
43	4094	462.0	16.18	.592	.898	.531	.713	.745	2.87	3.65	2.47	TUG
44	3138c	364.0	12.74	.618	.862	.532	.695	.766	2.67	4.22	2.36	TUG

Appendix (D)

Sample Calculation Sheet

TABLE II
- SAMPLE CALCULATION -

MODEL No: 4085 APPENDAGES: RUDDER TYPE: TUG TEST DATE: JULY 1949 SERIAL No: 36

MODEL RANGE $\lambda = 36$ $\lambda^2 = 1297$ $\lambda^3 = 46{,}600$ $\lambda^{1/2} = 6$ 400′ SHIP RANGE

Model range

$L = 11.11'$
$B = 2.733'$
$H = 1.00'$
$\Delta = 852^{\#}$
$S = 33.909\ \square'$
TEMP: 73°F
$\rho = 1.9355\ \#\ Sec^2/FT^4$
$\nu = 1.0147 \times 10^{-5}\ FT^2/SEC$

$\frac{1.689 L}{\nu} = 1.85 \times 10^6$ (1)

$\frac{1.689}{\sqrt{gL}} = .0894$ (2)

$a = 93.5$ (3)

$\Delta/(L/10)^3 = 285.5$
$\nabla/(.1L)^3 = 10.0$
$C_p = .596$
$C_x = .757$
$C_b = .451$
$C_{pv} = .622$
$C_w = .738$
$C_{sw} = 2.75$
$L/B = 4.08$
$B/H = 2.73$

400′ ship range

$L' = 400'$
$\Delta' = 18{,}220\ T$
$S' = 43{,}800\ \square'$
TEMP: 59°F
$\rho = 1.9905\ \#\ Sec^2/FT^4$
$\nu = 1.2817 \times 10^{-5}\ FT^2/SEC$
$\Delta C_f = .0004$

$A' = 382$ (4)
$\Delta'^{1/6} = 5.12$
$\Delta'^{2/3} = 692.4$

$\frac{.5834}{\Delta'^{1/6}} = .1136$ (5)

$\frac{427.1\ A'}{\Delta'^{2/3}} = 235.5$ (6)

V_K	R_T	aV_K^2	V_K^2	R_e	C_t	C_f	C_R	$V/\sqrt{gL}$
1.00	.45	93.5	1.00	1.85×10^6	4.78×10^{-3}	3.93×10^{-3}	$.85 \times 10^{-3}$	.0894
1.50	.99	210.5	2.25	2.78	4.71	3.65	1.06	.1341
1.75	1.35	286.0	3.06	3.24	4.71	3.55	1.16	.1565
2.00	1.77	374.0	4.00	3.70	4.74	3.47	1.27	.1789
2.25	2.28	473.0	5.07	4.16	4.82	3.40	1.42	.2012
2.50	2.90	585.0	6.25	4.62	4.97	3.34	1.63	.2237
2.75	3.22	706.0	7.56	5.09	5.25	3.28	1.97	.2460
3.00	4.91	841.0	9.00	5.55	5.84	3.24	2.60	.2685
3.25	6.44	988.0	10.57	6.01	6.52	3.19	3.30	.2905
3.50	8.29	1143.0	12.25	6.48	7.25	3.15	4.10	.3130
3.75	10.50	1316.0	14.07	6.94	7.99	3.12	4.87	.3355
4.00	13.25	1497.0	16.00	7.40	8.85	3.08	5.77	.3580
4.10	15.01	1571.0	16.80	7.59	9.55	3.07	6.48	.3670
4.20	17.05	1650.0	17.63	7.77	10.34	3.06	7.28	.3760
4.30	19.50	1730.0	18.50	7.95	11.29	3.05	8.24	.3845
4.40	22.65	1810.0	19.37	8.14	12.52	3.03	9.48	.3935
4.50	26.80	1892.0	20.25	8.32	14.14	3.02	11.12	.4030

$V/\sqrt{gL}$	C_R	C_f	$C_f + \Delta C_f$	C_t	V_K'	Ⓚ	Ⓒ
.05	1.00×10^{-3}	1.916×10^{-3}	2.316×10^{-3}	3.316×10^{-7}	3.36	.382	.782
.10	1.00	1.748	2.148	3.148	6.72	.763	.744
.15	1.12	1.657	2.057	3.177	10.06	1.141	.750
.20	1.42	1.597	1.997	3.417	13.41	1.522	.806
.25	2.09	1.554	1.954	4.044	16.77	1.903	.854
.30	3.66	1.520	1.920	5.580	20.15	2.285	1.317
.35	5.40	1.492	1.892	7.292	23.50	2.665	1.718
.40	10.50	1.467	1.867	12.367	26.85	3.050	2.920

1. REYNOLDS No: $\frac{1.689 V_K L}{\nu}$

2. FROUDE No: $\frac{1.689 V_K}{\sqrt{gL}}$

3. $C_t = \frac{R_T}{\frac{1}{2}\rho S (1.689 V_K)^2} = \frac{R_T}{a V_K^2}$

   $a = 1.426 \rho S$

4. $EHP_t = \frac{\frac{1}{2}\rho S (1.689 V_K)^3 C_t}{550} = A V_K^3 C_t$

   $A = \frac{\frac{1}{2}\rho S (1.689)^3}{550}$

5. Ⓚ $= \frac{.5834}{\Delta'^{1/6}} V_K'$

6. Ⓒ $= \frac{427.1}{\Delta'^{2/3} V_K'^3} EHP_t' = \frac{427.1 A' C_t'}{\Delta'^{2/3}}$

7. $C_R = C_t - C_f$

8. $\frac{.242}{\sqrt{C_f}} = \log_{10}(R_e C_f)$

Appendix (E)

Curves of Residual Resistance Coefficient vs. Froude Numbers, both Calculated and as Predicted from the Contours. Curves of C vs. K.

Original Model Test Data

FIGURE XIII

MODEL No: 2433

SERIAL No: 1

L = 20.23'
B = 3.622'
H = 1.536' EK
Δ = 5538#
S = 115.497 □'
L/B = 5.58
B/H = 2.36

C_p = .80
∇/L^3 = 10.7
C_x = .984
C_B = .787
C_{PV} = .89
C_W = .89
C_{SW} = 2.72

APPENDAGES: RUDDER
TYPE: SUCTION DREDGE (USAE)
SINGLE SCREW

MODEL DATA

TEMP = 62°F

V_k	R_T
.6	.62
.8	1.00
1.0	1.46
1.3	2.32
1.5	3.02
1.7	3.83
2.0	5.30
2.3	7.08
2.5	8.50
2.7	10.18
3.0	13.50
3.1	14.95
3.2	16.80
3.3	19.40

© vs ® FOR 400' SHIP
ΔC_f = .0004
TEMP. 59°F

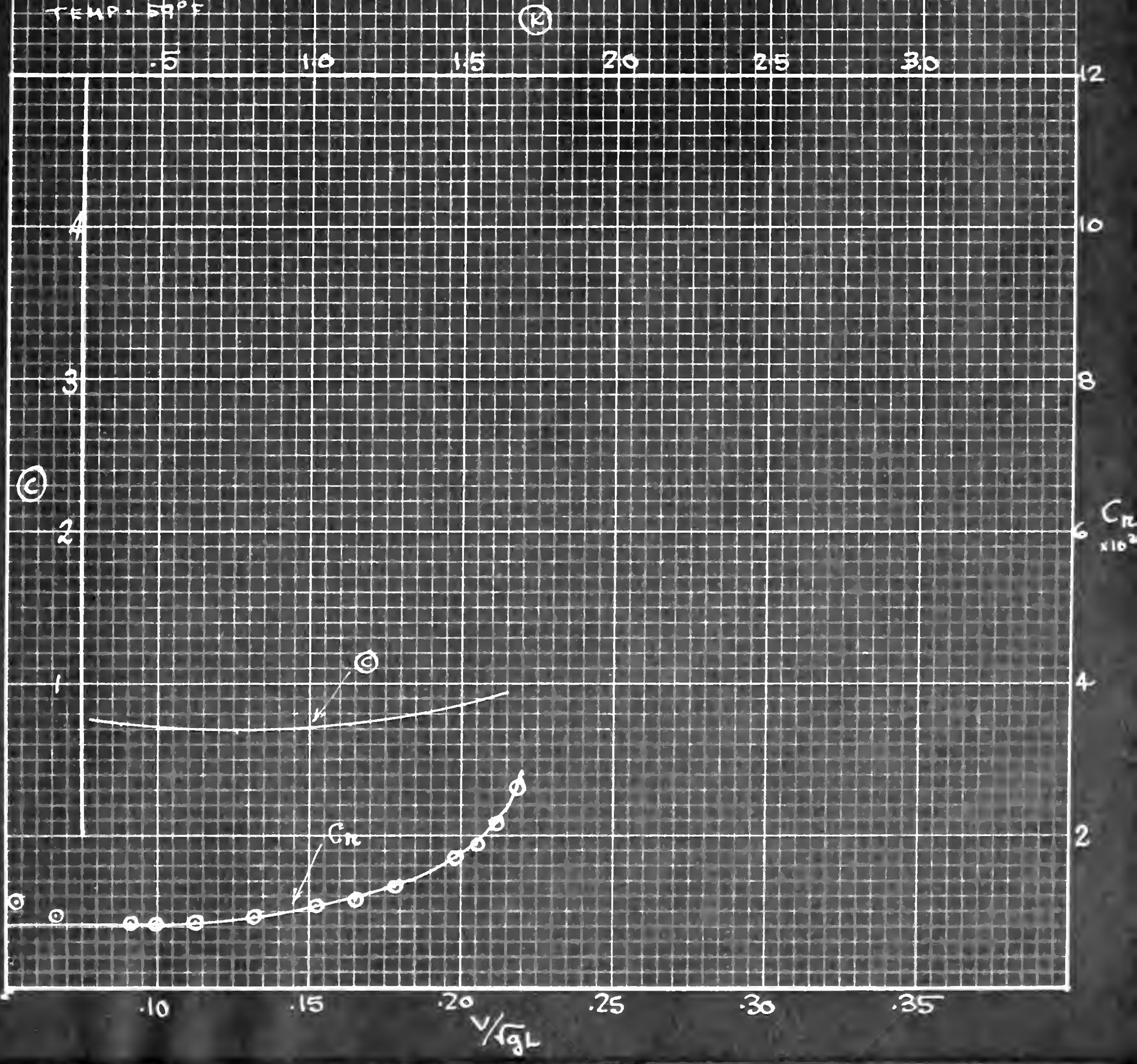
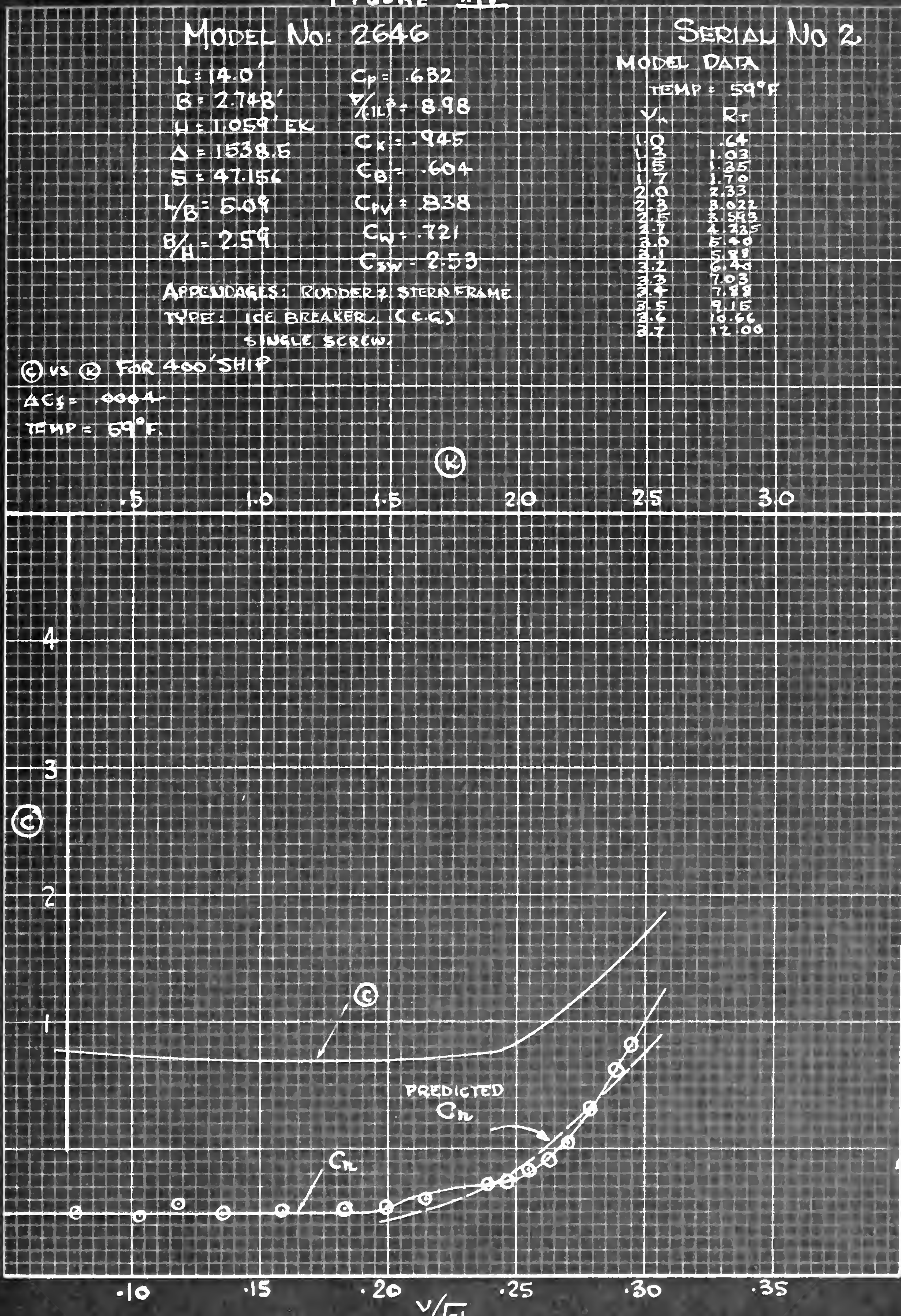


FIGURE XIV



MODEL No: 2646
SERIAL No 2
L = 14.0'
B = 2.748'
H = 1.059' EK
Δ = 1538.5
S = 47.156
L/B = 5.09
B/H = 2.59
Cp = .632
∇/(.1L)³ = 8.98
Cx = .945
CB = .604
Cpv = .838
Cw = .721
Csw = 2.53
APPENDAGES: RUDDER & STERN FRAME
TYPE: ICE BREAKER (C.G.)
SINGLE SCREW.
MODEL DATA
TEMP = 59°F
Vk Rt
1.0 .64
1.3 1.03
1.5 1.35
1.7 1.70
2.0 2.33
2.3 3.022
2.5 3.593
2.7 4.235
3.0 5.40
3.1 5.89
3.2 6.40
3.3 7.03
3.4 7.88
3.5 9.15
3.6 10.66
3.7 12.00
© vs ® FOR 400' SHIP
ΔCf = .0004
TEMP = 59°F.
K
.5
1.0
1.5
2.0
2.5
3.0
12
10
8
6
4
2
Cr ×10³
4
3
2
1
C
PREDICTED Cr
Cr
.10
.15
.20
.25
.30
.35
V/√gL

FIGURE XV

MODEL No: 2834

SERIAL No: 3

L = 14.3′	C_p = .659
B = 3.15′	$\nabla/(L/100)^3$ = 9.10
H = .95′F 1.15′A	C_x = .871
Δ = 1663 #	C_b = .573
S = 55.0 □′	C_{PV} = .747
L/B = 4.54	C_w = .768
B/H = 3.00	C_{SW} = 2.82

APPENDAGES: RUDDER, BILGE KEEL

TYPE: SURVEY SHIP (C&GS)

MODEL DATA

TEMP: 70°F

V_k	R_T
1.00	.66
1.30	1.10
1.50	1.46
1.70	1.88
2.00	2.60
2.30	3.44
2.50	4.11
2.70	4.88
3.00	6.33
3.20	7.99
3.40	9.24
3.60	11.59
3.80	14.88
4.00	18.76
4.20	23.26

Ⓒ VS Ⓚ FOR 400′ SHIP

ΔC_f = .0004

TEMP = 59°F

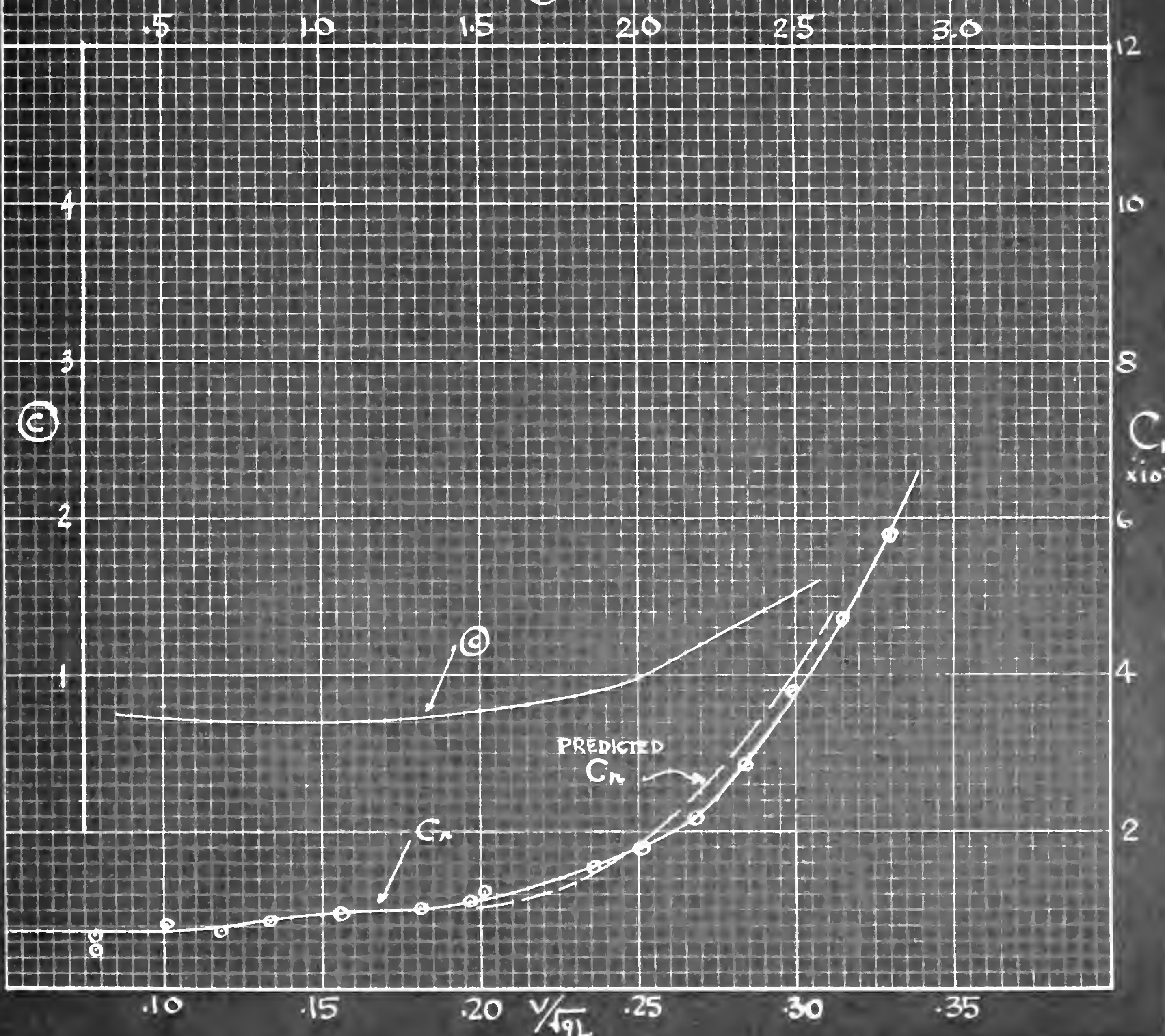


FIGURE XVI

MODEL NO: 3064 (4-1-0)

SERIAL NO 4

L = 8.75'
B = 2.50'
H = 1.0'
Δ = 802#
S = 28.78 □'
L/B = 3.50
B/H = 2.5

C_P = .593
$\nabla/(.1L)^3$ = 19.20
C_X = .99
C_B = .588
C_{PV} =
C_W =
C_{SW} = 2.72

MODEL DATA
TEMP = 68°F

V_M	R_T
1.0	.45
1.5	.94
1.75	1.30
2.0	1.78
2.25	2.40
2.50	3.26
2.75	4.50
3.0	6.94

APPENDAGES: NONE
TYPE: SERIES 53 PMB (S.B.)

Ⓒ VS Ⓚ FOR 400' SHIP
ΔC_f = .0004
TEMP = 59°F

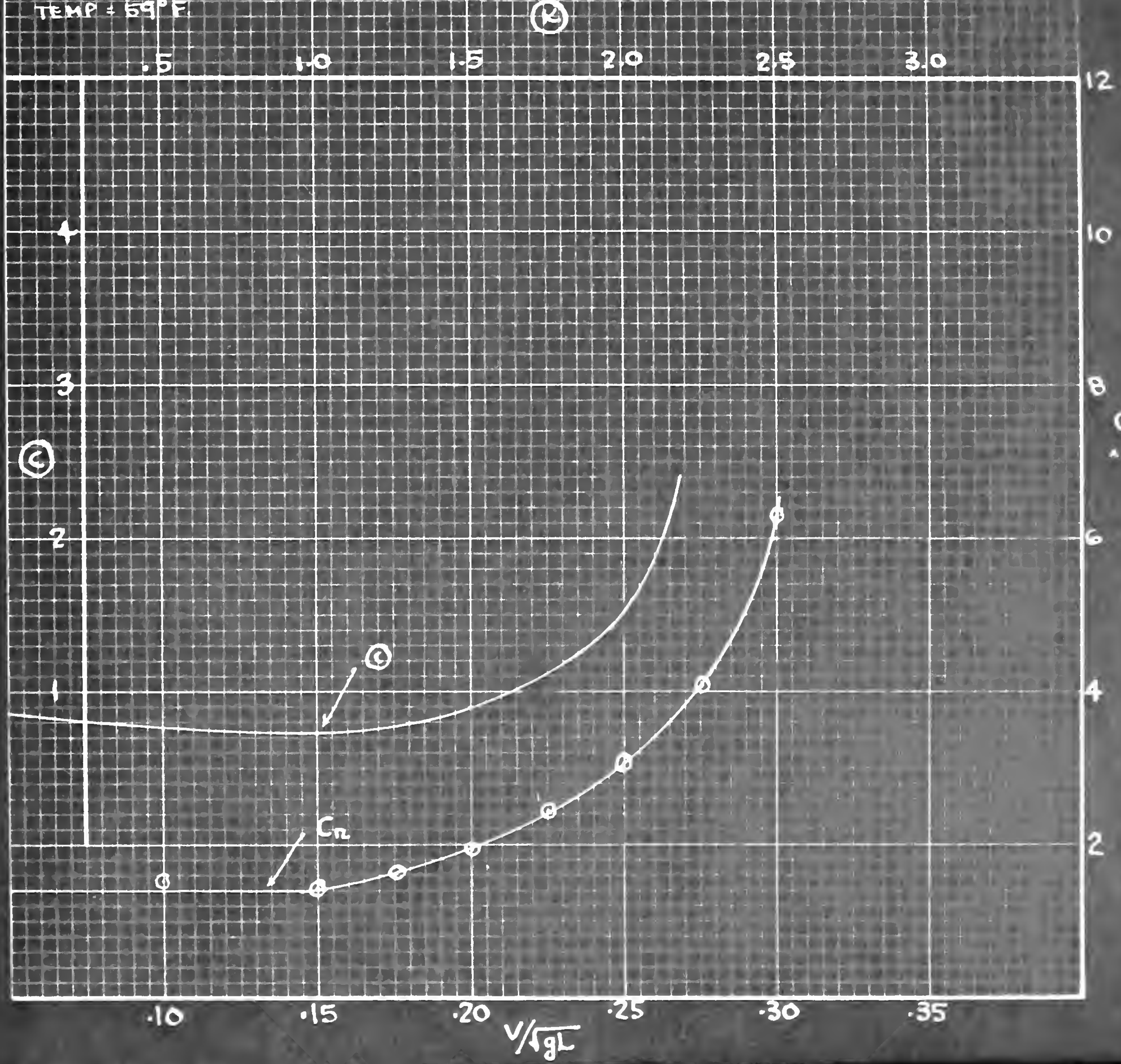


FIGURE XVII

MODEL NO: 3064
(4-1-5)

SERIAL NO 5

$L = 9.25'$
$B = 2.50'$
$H = 1.00'$
$\Delta = 880\#$
$S = 3095 \square'$
$L/B = 3.70$
$B/H = 2.50$

$C_p = .616$
$\nabla/(.1L)^3 = 17.9$
$C_x = .99$
$C_B = .611$
$C_{PV} =$
$C_W =$
$C_{SW} = 2.72$

APPENDAGES: NONE
TYPE : SERIES 53 PMB -(S.B.)

MODEL DATA
TEMP = 67°

V_K	R_T
1.0	.47
1.5	1.01
1.75	1.43
2.00	1.93
2.25	2.67
2.50	3.93
2.75	5.50
3.00	7.74
3.10	9.75

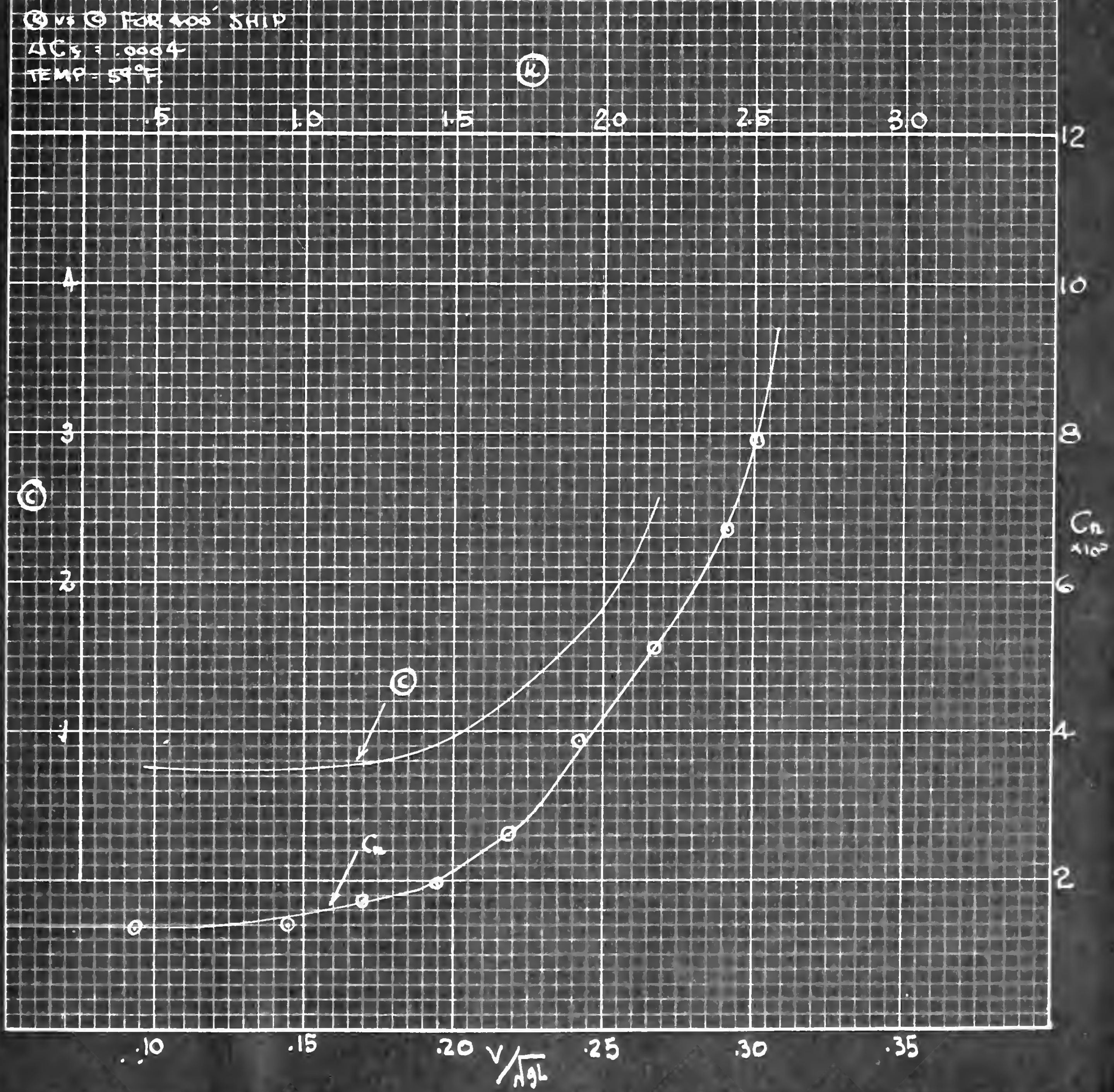


FIGURE XVIII

MODEL NO: 3064
(4-1-1)

SERIAL NO: 6

MODEL DATA

TEMP = 66°F

V_m	R_t
1.00	.48
1.50	1.02
1.75	1.40
2.00	1.88
2.25	2.66
2.50	4.20
2.75	6.40
3.00	9.26
3.10	10.50

L = 9.75'	C_P = .635
B = 2.50'	$\nabla/(L/10)^3$ = 16.65
H = 1.00'	C_X = .99
Δ = 957#	C_B = .631
S = 33.11 ft²	C_{PW} =
L/B = 3.90	C_W =
B/H = 2.50	C_{SW} = 2.72

APPENDAGES: NONE

TYPE: SERIES 53 PHB (S.B.)

Ⓒ vs Ⓚ FOR 400' SHIP

ΔC_f = .0004

TEMP = 59°F

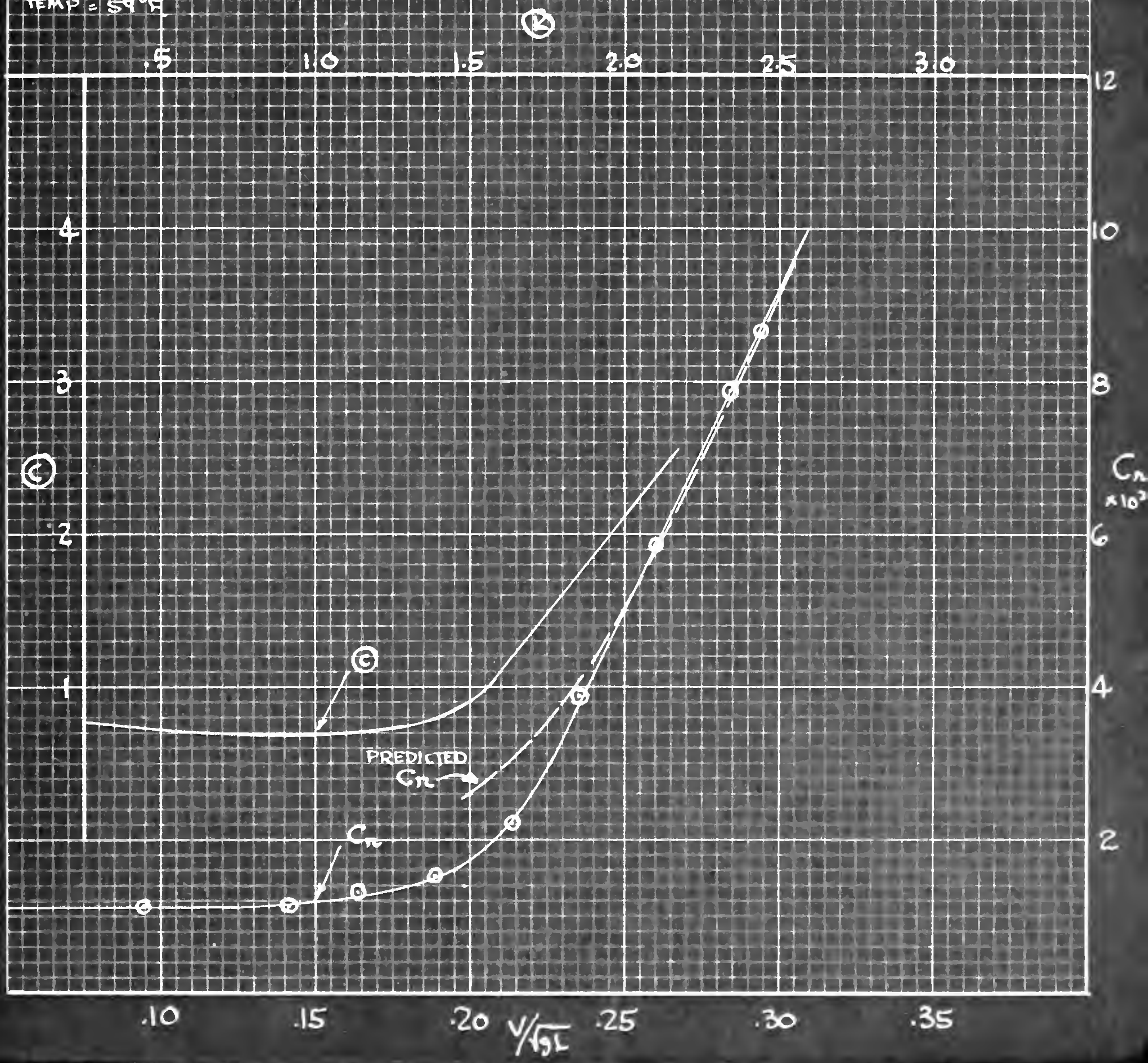


FIGURE XIX

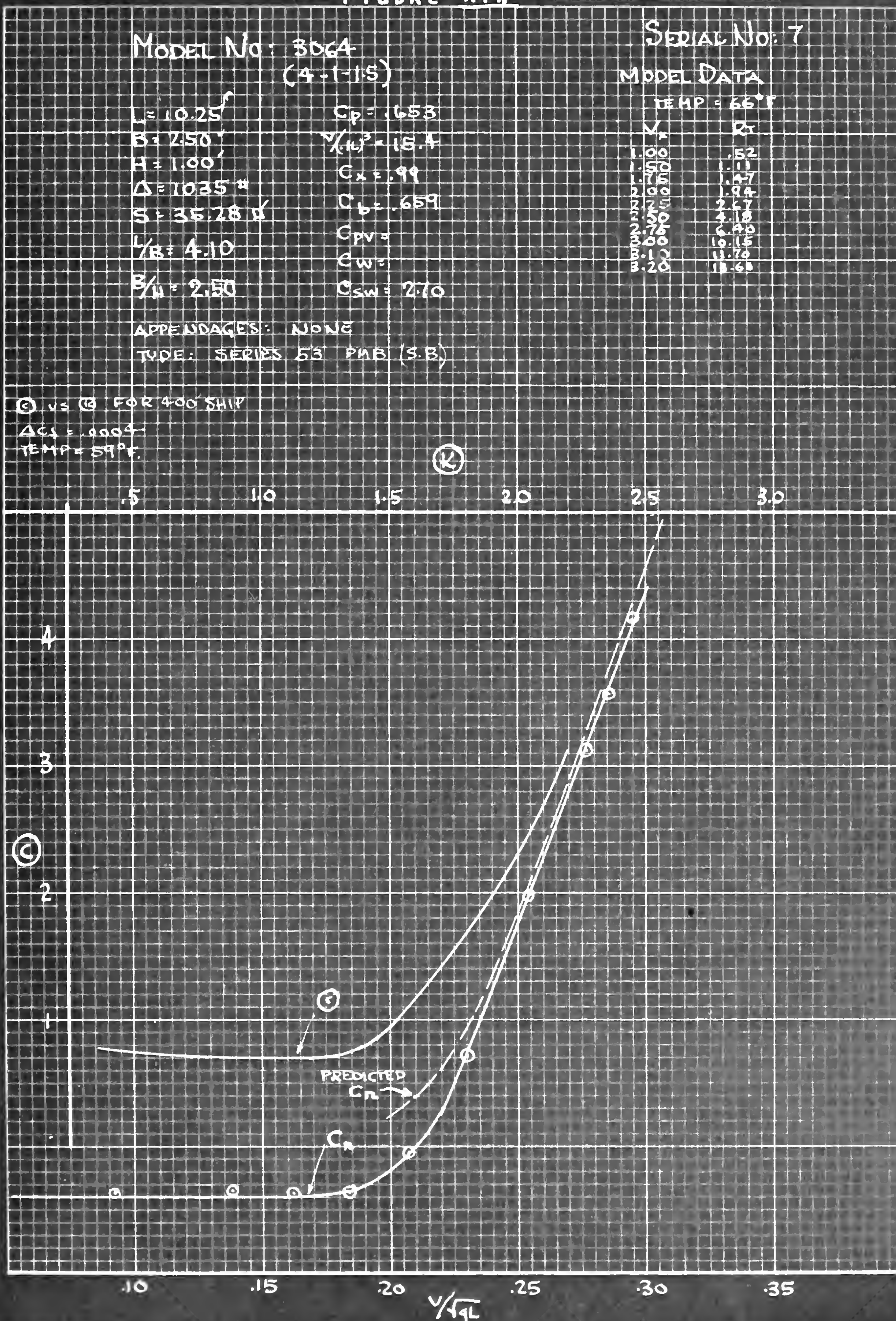

MODEL NO: 3064
(4-1-15)
SERIAL NO: 7
L = 10.25
B = 2.50
H = 1.00
Δ = 1035 #
S = 35.28
L/B = 4.10
B/H = 2.50
Cp = .653
∇/(L)³ = 15.4
Cx = .99
Cb = .659
Cpv =
Cw =
Csw = 2.70
MODEL DATA
TEMP = 66°F
V
RT
1.00 .52
1.50 1.11
1.75 1.47
2.00 1.94
2.25 2.67
2.50 4.18
2.75 6.40
3.00 10.15
3.12 11.70
3.20 13.68
APPENDAGES: NONE
TYPE: SERIES 53 PMB (S.B)
C VS K FOR 400' SHIP
ΔCf = .0004
TEMP = 59°F
K
.5
1.0
1.5
2.0
2.5
3.0
12
10
8
6
4
2
4
3
2
1
C
CR x10³
C
PREDICTED CR
CR
.10
.15
.20
.25
.30
.35
V/√gL

FIGURE XX

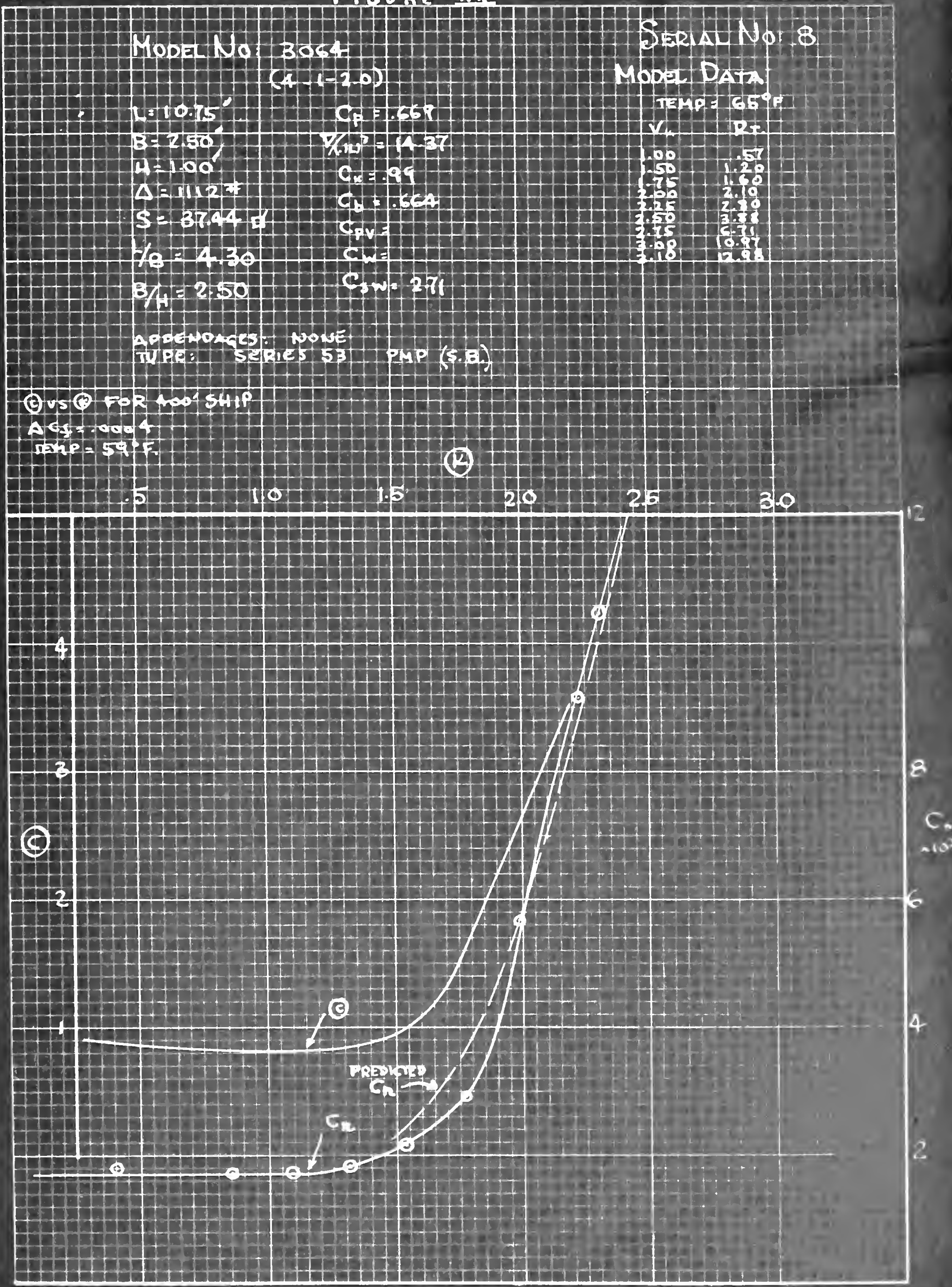

MODEL NO: 3064
(4-1-2.0)
L=10.75'
B=2.50'
H=1.00'
Δ=1112#
S=37.44 □'
L/B=4.30
B/H=2.50
C_P=.669
∇/(.1L)³=14.37
C_X=.99
C_b=.664
C_{PV}=
C_W=
C_{SW}=2.71
SERIAL NO: 8
MODEL DATA
TEMP = 65°F
V. RT.
1.00 .57
1.50 1.20
1.75 1.60
2.00 2.10
2.25 2.80
2.50 3.38
2.75 6.71
3.00 10.97
3.10 12.98
APPENDAGES: NONE
TYPE: SERIES 53 PMP (S.B.)
© vs ® FOR 400' SHIP
ΔC_f=.0004
TEMP=59°F
®
.5 1.0 1.5 2.0 2.5 3.0
©
1 2 3 4
2 4 6 8 12
C_R ×10³
PREDICTED C_R
C_R
.10 .15 .20 .25 .30 .35
V/√gL

FIGURE XXI

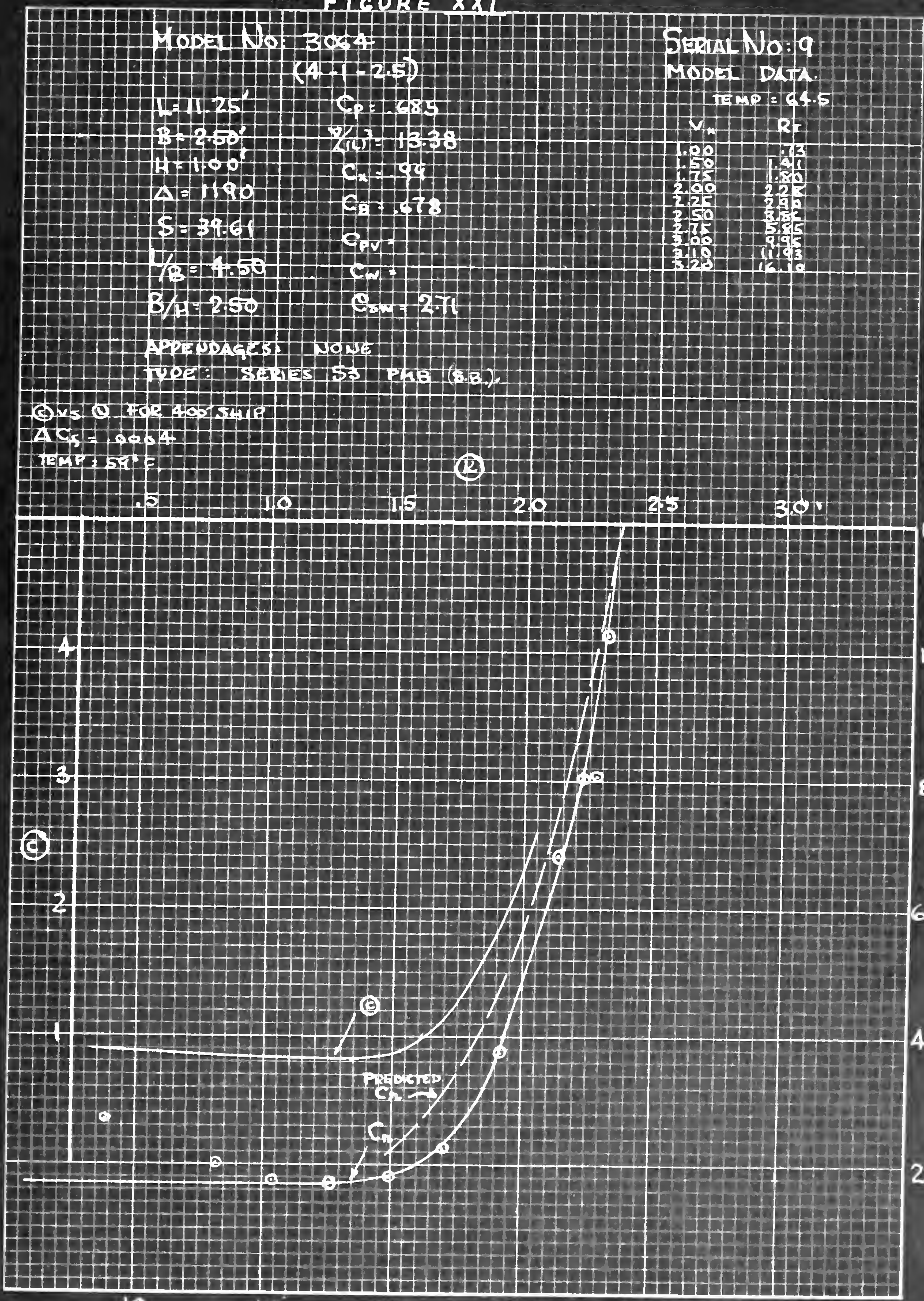
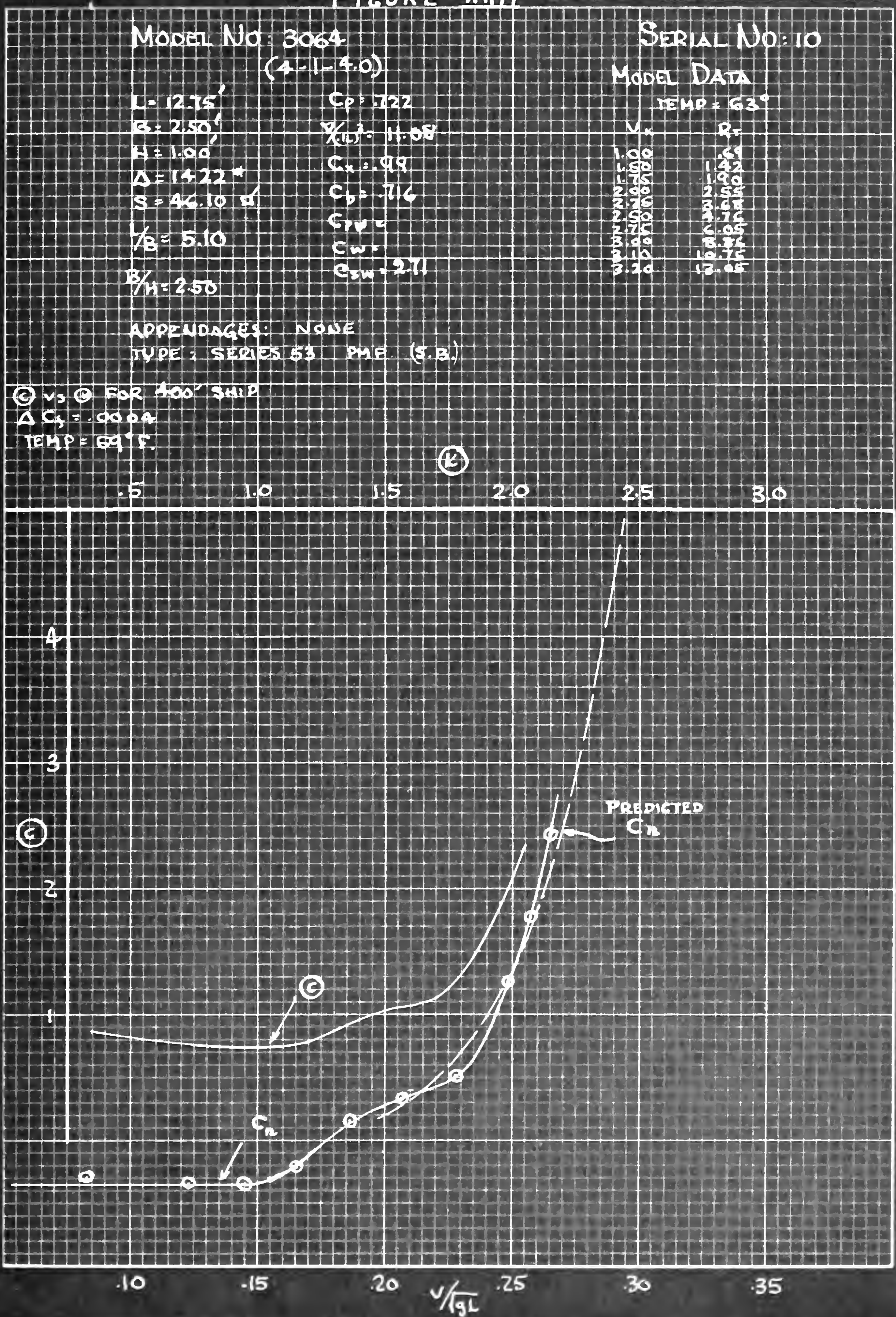

MODEL NO: 3064
(4-1-2.5)
L = 11.25'
B = 2.50'
H = 1.00'
Δ = 1190
S = 39.61
L/B = 4.50
B/H = 2.50
Cp = .685
∇/(L)³ = 13.38
Cx = .99
CB = .678
CPV =
CW =
CSW = 2.71
SERIAL NO: 9
MODEL DATA.
TEMP = 64.5
Vk Rt
1.00 .73
1.50 1.41
1.75 1.80
2.00 2.28
2.25 2.90
2.50 3.82
2.75 5.85
3.00 9.95
3.10 11.93
3.20 12.10
APPENDAGES: NONE
TYPE: SERIES 53 PMB (S.B.)
Ⓒ VS Ⓚ FOR 400' SHIP
ΔCf = .0004
TEMP: 59° F.
Ⓚ
.5 1.0 1.5 2.0 2.5 3.0
Ⓒ
1 2 3 4
2 4 6 8 10 12
Cn ×10³
Ⓒ
PREDICTED Cn
Cn
.10 .15 .20 .25 .30 .35
V/√gL

FIGURE XXII



MODEL NO: 3064
(4-1-4.0)
SERIAL NO: 10
L = 12.75'
B = 2.50'
H = 1.00'
Δ = 1422 #
S = 46.10 □'
L/B = 5.10
B/H = 2.50
Cp = .722
∇/(L)³ = 11.08
Cx = .99
Cb = .716
Cpw =
Cw =
Csw = 2.71
MODEL DATA
TEMP = 63°
Vk Rt
1.00 .69
1.50 1.42
1.75 1.90
2.00 2.55
2.25 3.68
2.50 4.76
2.75 6.05
3.00 8.36
3.10 10.75
3.20 12.05
APPENDAGES: NONE
TYPE: SERIES 53 PMB (S.B.)
© vs Ⓚ FOR 400' SHIP
Δ Cf = .0004
TEMP = 69°F.
Ⓚ
.5
1.0
1.5
2.0
2.5
3.0
©
PREDICTED Cn
Cn
.10
.15
.20
.25
.30
.35
V/√gL

FIGURE XXIII

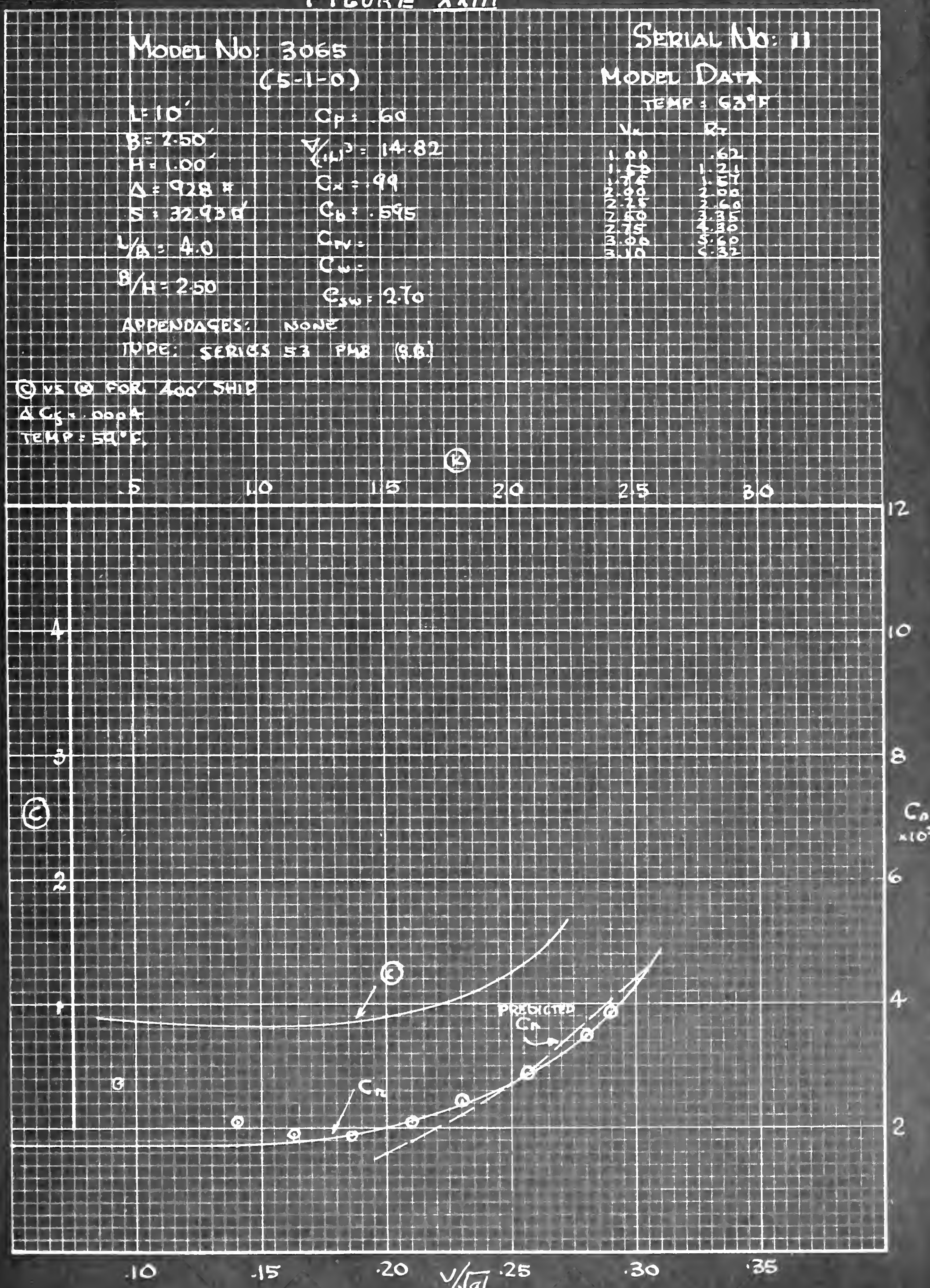


FIGURE XXIV

MODEL NO: 3065 (5-4.5) SERIAL NO 12

L = 10.5′	C_P = .620
B = 2.50′	∇/L^3 = 13.90
H = 1.00′	C_X = .99
Δ = 1005 #	C_B = .614
S = 35.09 □′	C_{PV} =
L/B = 4.2	C_W =
B/H = 2.50	C_{SW} = 2.70

MODEL DATA

TEMP = 43°

V_K	R_T
1.00	.47
1.50	1.01
1.75	1.40
2.00	1.93
2.25	2.61
2.50	3.51
2.75	4.74
3.00	6.39
3.10	7.27
3.20	8.32
3.30	10.10

APPENDAGES: NONE

TYPE: SERIES 53 PMB (S.B)

Ⓒ VS Ⓚ FOR 400′ SHIP

ΔC_f = .0004

TEMP = 59° F.

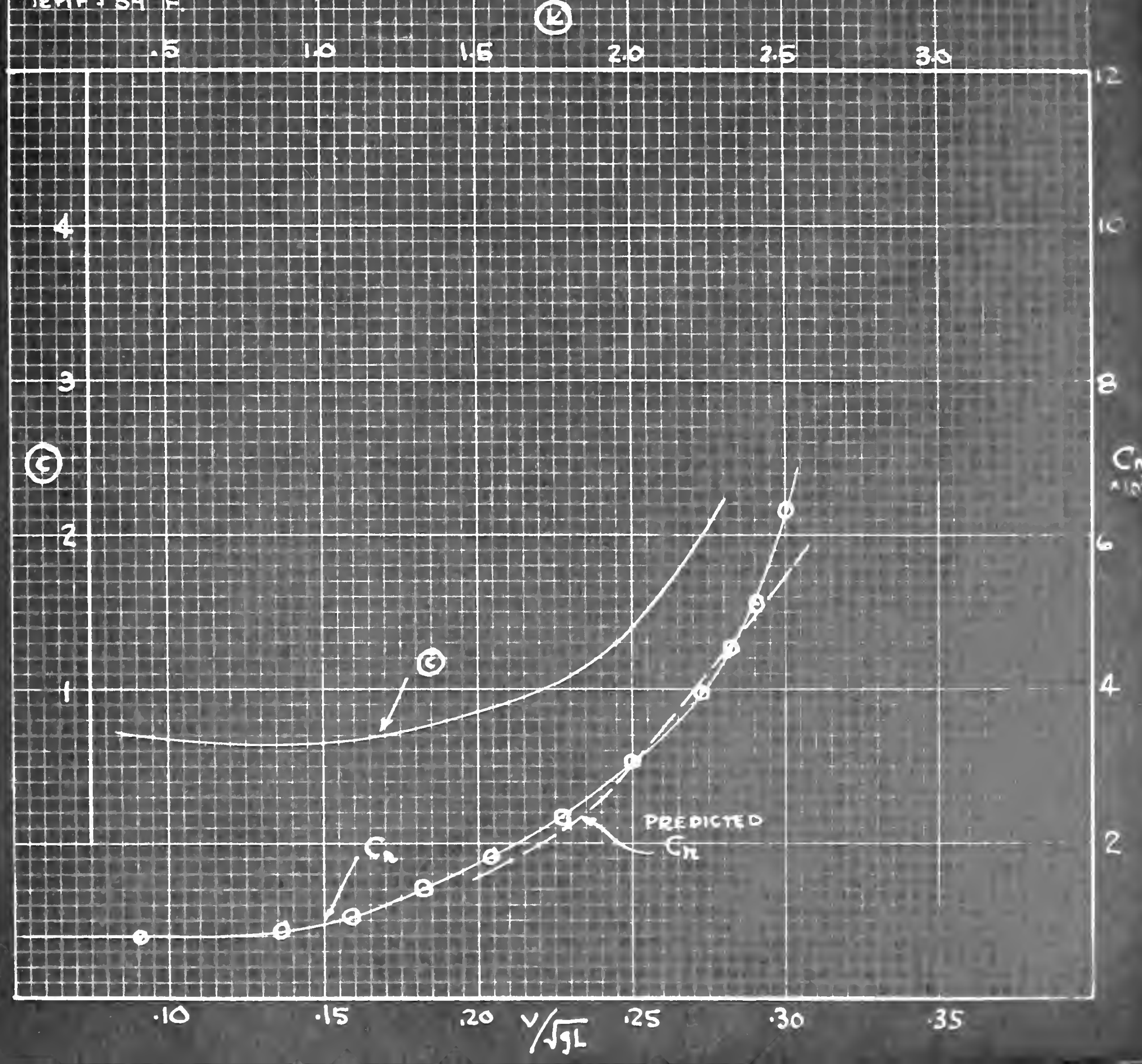


FIGURE XXV

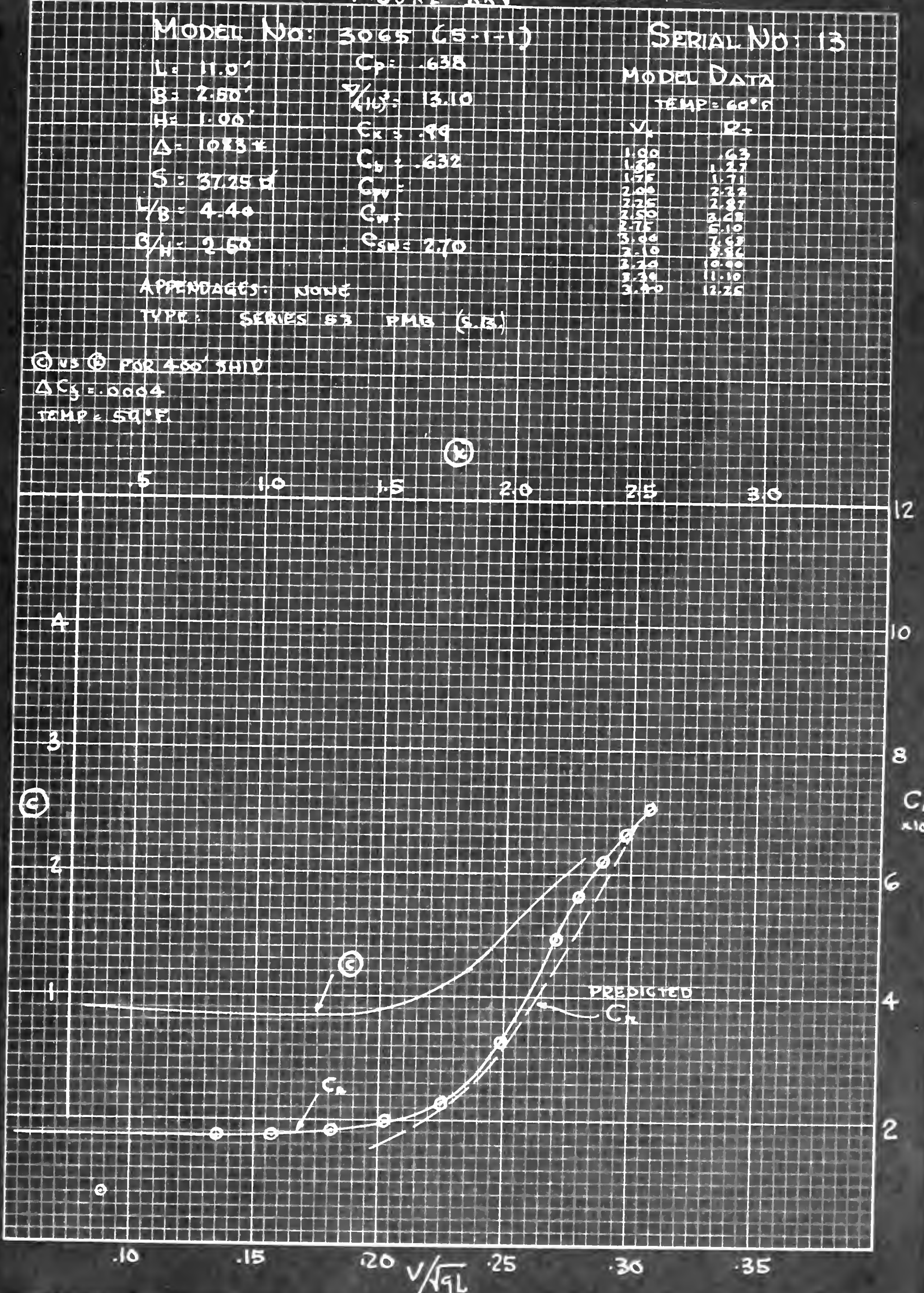
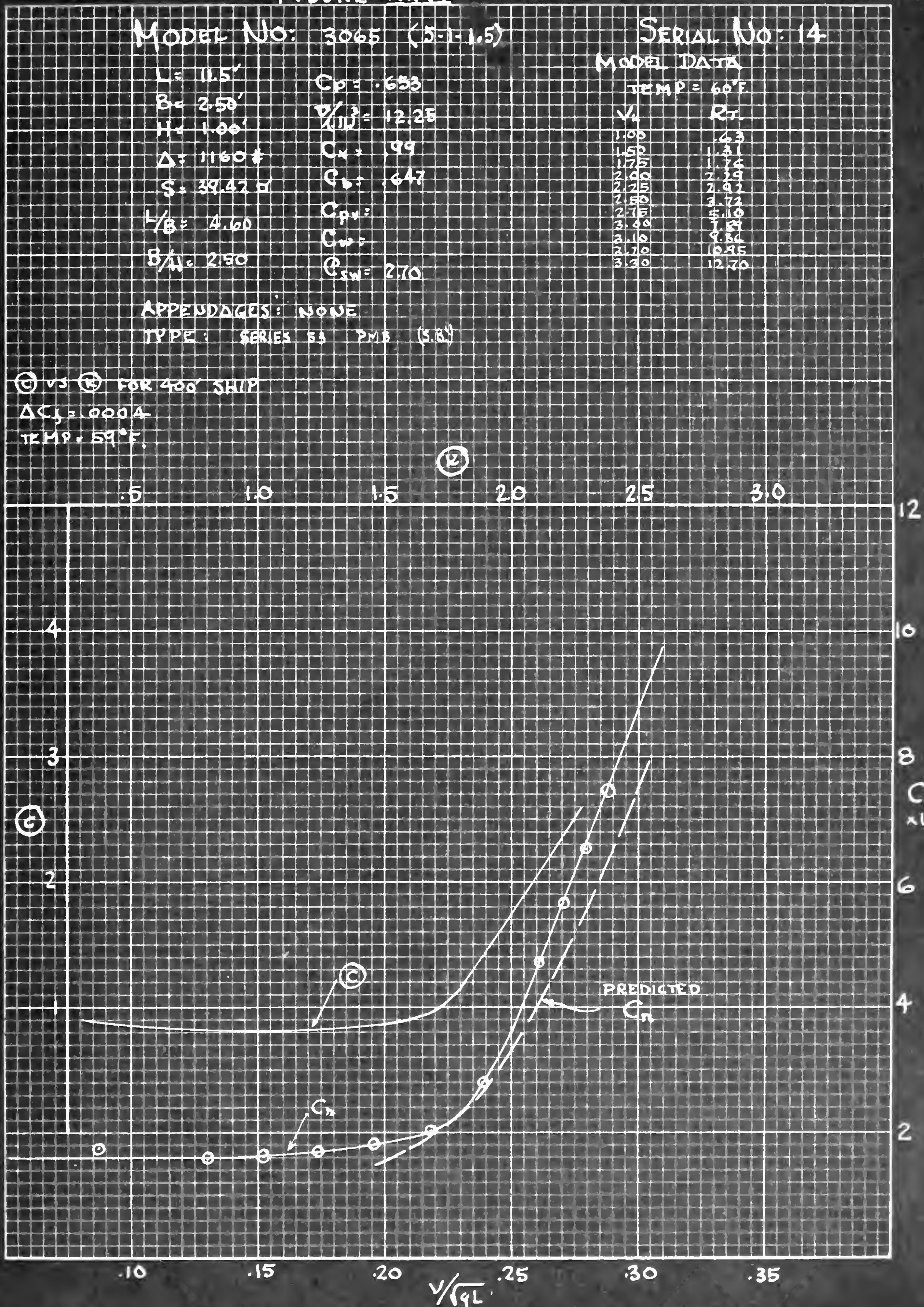

MODEL NO: 3065 (5-1-1)
SERIAL NO: 13
L = 11.0'
B = 2.50'
H = 1.00'
Δ = 1033 #
S = 37.25 ▢'
L/B = 4.40
B/H = 2.50
Cp = .638
∇/(L/10)³ = 13.10
Cx = .99
Cb = .632
Cpv =
Cw =
Csw = 2.70
MODEL DATA
TEMP = 60°F
V R
1.00 .63
1.50 1.27
1.75 1.71
2.00 2.22
2.25 2.87
2.50 3.68
2.75 5.10
3.00 7.63
3.10 9.86
3.20 10.00
3.30 11.10
3.40 12.25
APPENDAGES: NONE
TYPE: SERIES 53 PMB (S.B.)
© vs Ⓚ FOR 400' SHIP
ΔCf = .0004
TEMP = 59°F
Ⓚ
.5
1.0
1.5
2.0
2.5
3.0
12
10
8
6
4
2
4
3
2
1
©
Cr x10³
PREDICTED
Cr
Cr
.10
.15
.20
.25
.30
.35
V/√gL

FIGURE XXVI



MODEL NO: 3065 (5-1-1.5)
SERIAL NO: 14
L = 11.5'
B = 2.50'
H = 1.00'
Δ = 1160#
S = 39.42 □'
L/B = 4.60
B/H = 2.50
Cp = .653
∇/(L/100)³ = 12.25
Cx = .99
Cb = .647
Cpv =
Cw =
Ⓒsw = 2.70
MODEL DATA
TEMP = 60°F
Vk RT
1.00 .63
1.50 1.31
1.75 1.74
2.00 2.29
2.25 2.92
2.50 3.72
2.75 5.10
3.00 7.89
3.10 9.36
3.70 10.95
3.30 12.70
APPENDAGES: NONE
TYPE: SERIES 53 PMB (S.B.)
Ⓒ VS Ⓚ FOR 400' SHIP
ΔCf = .0004
TEMP = 59°F
Ⓚ
.5 1.0 1.5 2.0 2.5 3.0
Ⓒ
4 3 2 1
12 10 8 6 4 2
Cr ×10³
Ⓒ
PREDICTED Cr
Cr
.10 .15 .20 .25 .30 .35
V/√gL

FIGURE XXVII

MODEL NO: 3065 (5-1-2)

SERIAL NO: 15

L = 12.0'
B = 2.50'
H = 1.00'
Δ = 1238 #
S = 41.58 □'
L/B = 4.8
B/H = 2.50

C_p = .668
$\nabla/(L/10)^3$ = 1.44
C_x = .99
C_b = .661
C_{pv} =
C_w =
C_{sw} = 2.73

MODEL DATA
TEMP = 61°F

V_M	R_T
1.00	.70
1.50	1.47
1.75	1.90
2.00	2.37
2.25	2.85
2.50	3.64
2.75	4.90
3.00	7.20
3.10	9.55
3.20	11.45
3.30	13.95

APPENDAGES: NONE
TYPE: SERIES 53 PH8 (3.8)

Ⓒ VS Ⓚ FOR 400' SHIP
ΔC_f = .0004
TEMP = 50° F.

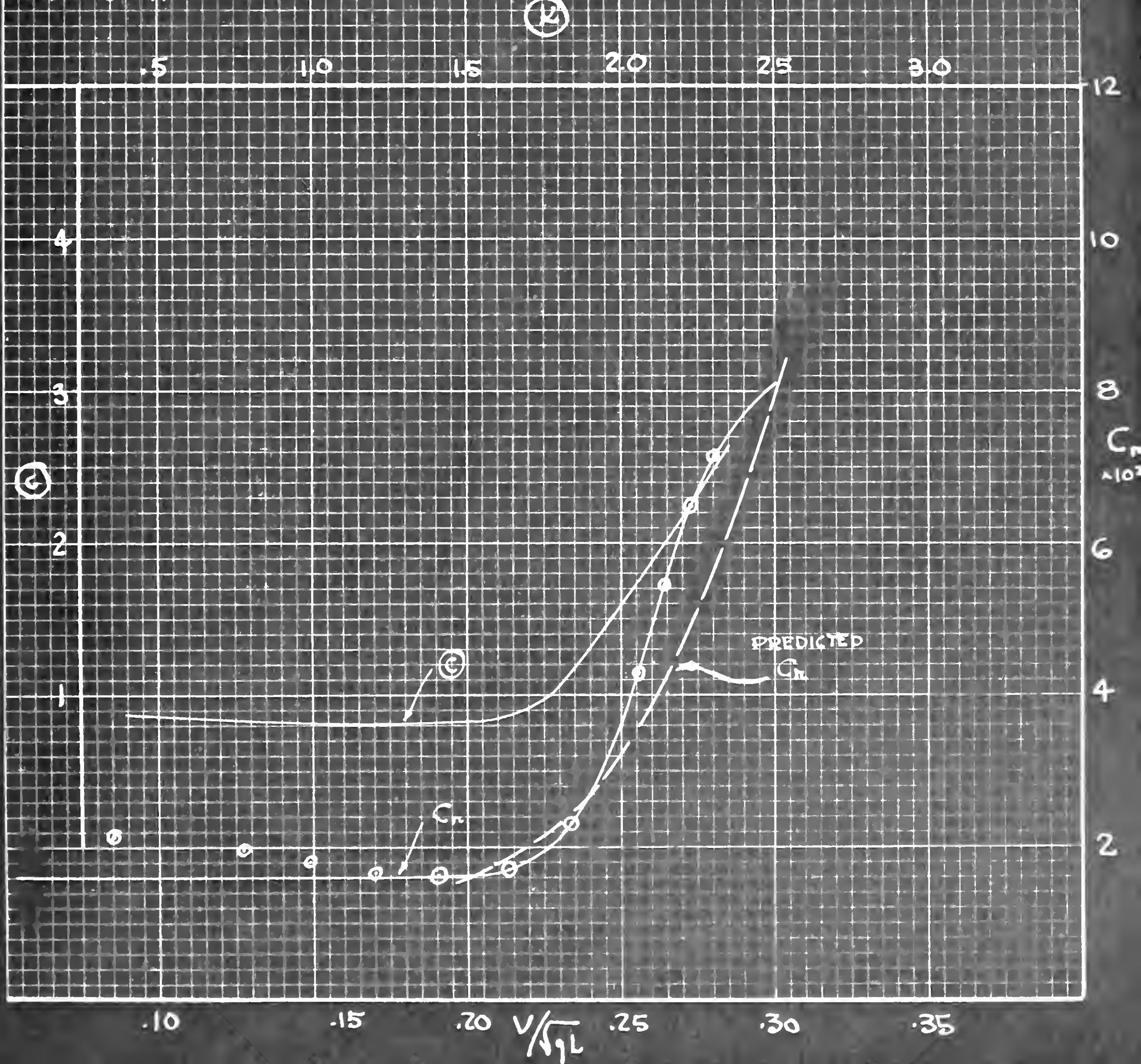


FIGURE XXVIII

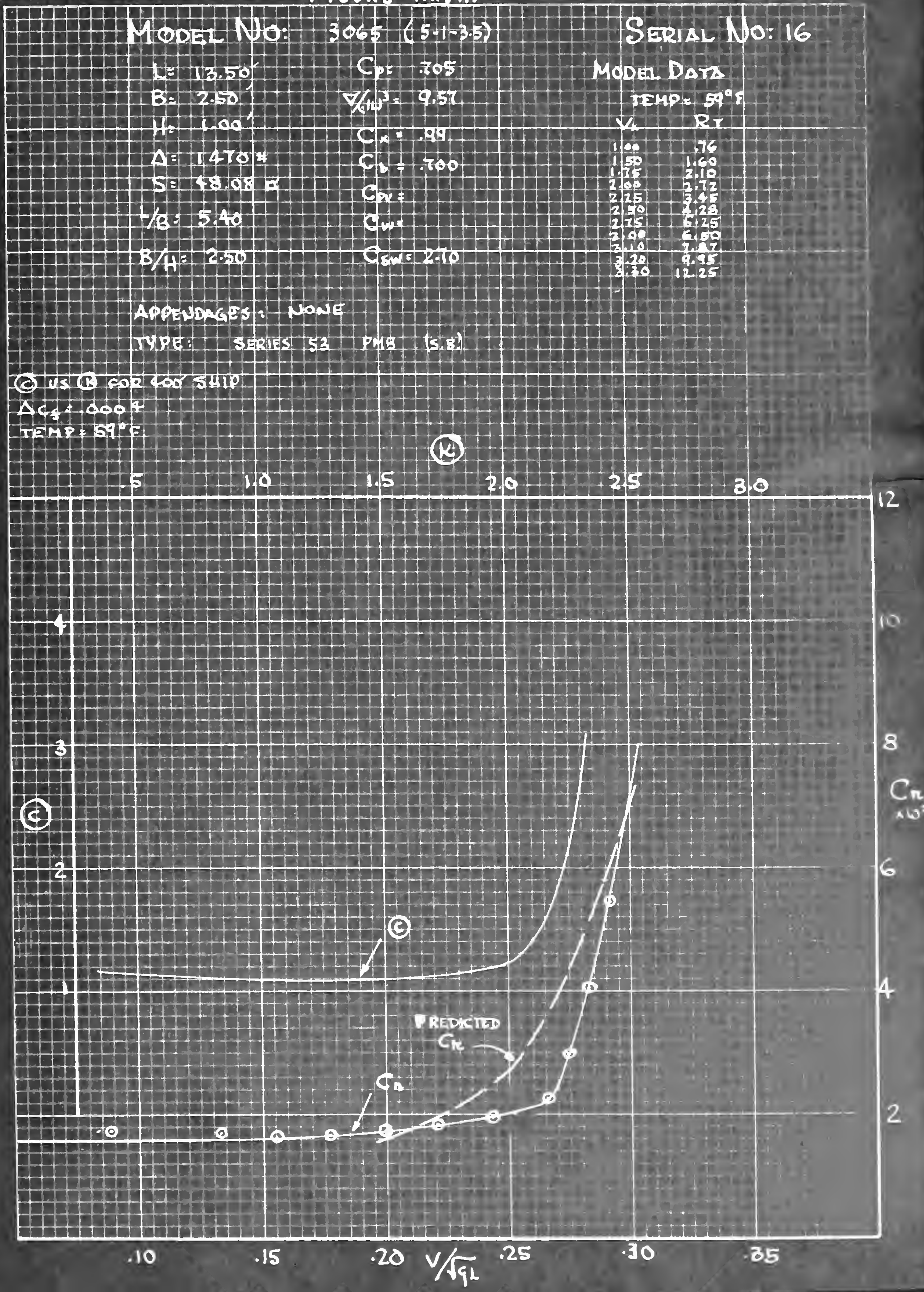


FIGURE XXIX

MODEL NO: 3068 (2-2-1)

SERIAL NO: 17

L = 12.25'
B = 2.50'
H = 1.00'
Δ = 1112#
S = 40.04 □'
L/B = 4.90
B/H = 2.50

C_p = .588
$\nabla/(L/10)^3$ = 9.69
C_x = .99
C_b = .584
C_{pv} =
C_w =
C_{sw} = 2.72

APPENDAGES: NONE
TYPE: SERIES 53 PHB (G.B.)

MODEL DATA
TEMP = 54°F

V_L	R_T
1.00	.61
1.50	1.25
1.75	1.63
2.00	2.12
2.25	2.80
2.50	3.52
2.75	4.17
3.00	4.98
3.10	5.50
3.20	6.16
3.30	7.03
3.40	8.10
3.50	9.90
3.60	10.48

Ⓒ vs Ⓚ FOR 400' SHIP
ΔC_f = .0004
TEMP = 59°F

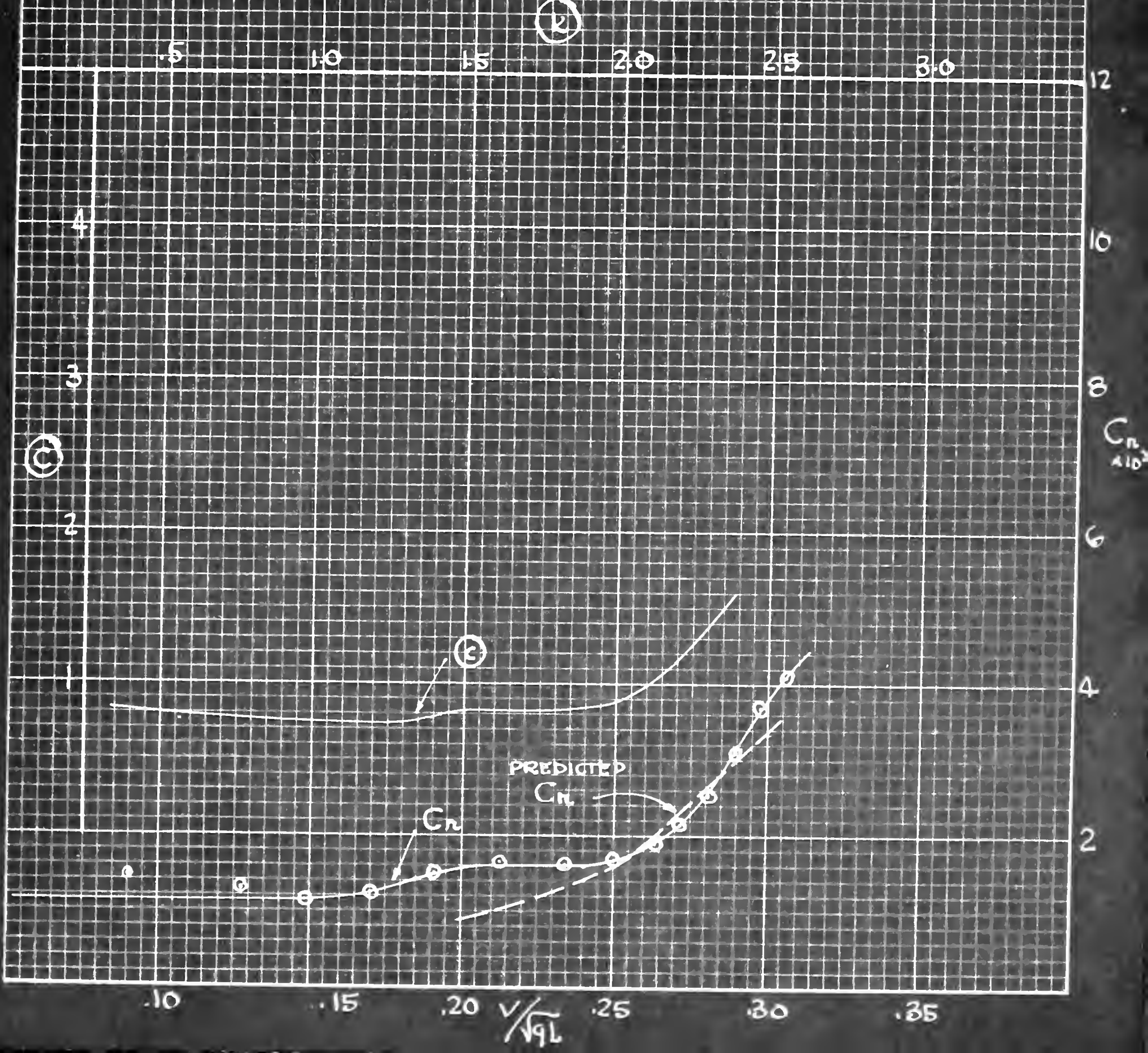


FIGURE XXX

MODEL No: 3070 (4-2-15) SERIAL No: 18

L = 11.50′
B = 2.50′
H = 1.00′
Δ = 1141 #
S = 39.19 ▫′
L/B = 4.60
B/H = 2.50

C_p = .642
$\nabla/(L/10)^3$ = 12.06
C_x = .99
C_b = .637
C_{pv} =
C_w =
C_{sw} = 2.71

MODEL DATA
TEMP: 54°F.

V_k	R_T
1.00	.66
1.50	1.41
1.75	1.86
2.00	2.38
2.25	2.98
2.50	4.13
2.75	6.66
3.00	10.27
3.10	11.85
3.20	13.75

APPENDAGES: NONE
TYPE: SERIES 53 PMB (S.B)

Ⓒ vs Ⓚ FOR 400′ SHIP
ΔC_f = .0004
TEMP = 59°F.

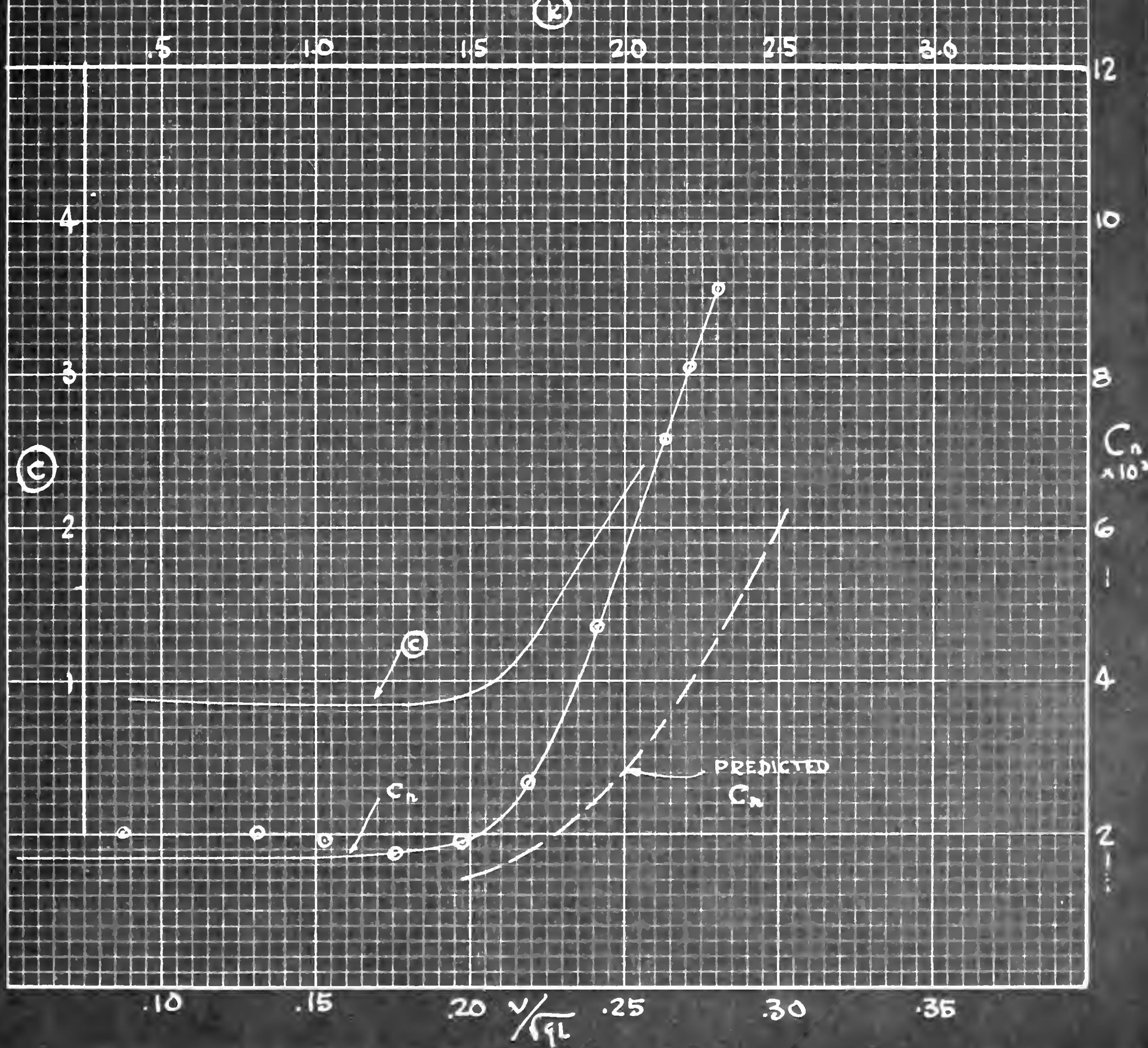


FIGURE XXXI

MODEL No: 3102 SERIAL No: 19

L = 15.0'
B = 3.583'
H = 1.200' (2' TRIMBS.)
Δ = 2145#
S = 57.711
L/B = 4.18
B/H = 2.99

C_p = .629
$\nabla/(\frac{L}{10})^3$ = 10.25
C_x = .848
C_b = .534
C_{pv} =
C_w =
C_{sw} = 2.54

MODEL DATA

TEMP: 71°F

V_K	R_T
1.00	.71
1.50	1.49
2.00	2.63
2.50	4.24
3.00	6.64
3.20	7.80
3.40	9.34
3.50	10.35
3.60	11.72
3.80	16.03
4.00	20.28
4.20	24.80
4.40	28.28
4.60	32.10

APPENDAGES: NONE
TYPE: COAST GUARD CUTTER (C.G)

Ⓒ vs Ⓚ FOR 400' SHIP
ΔC_f = .0004
TEMP = 59°F

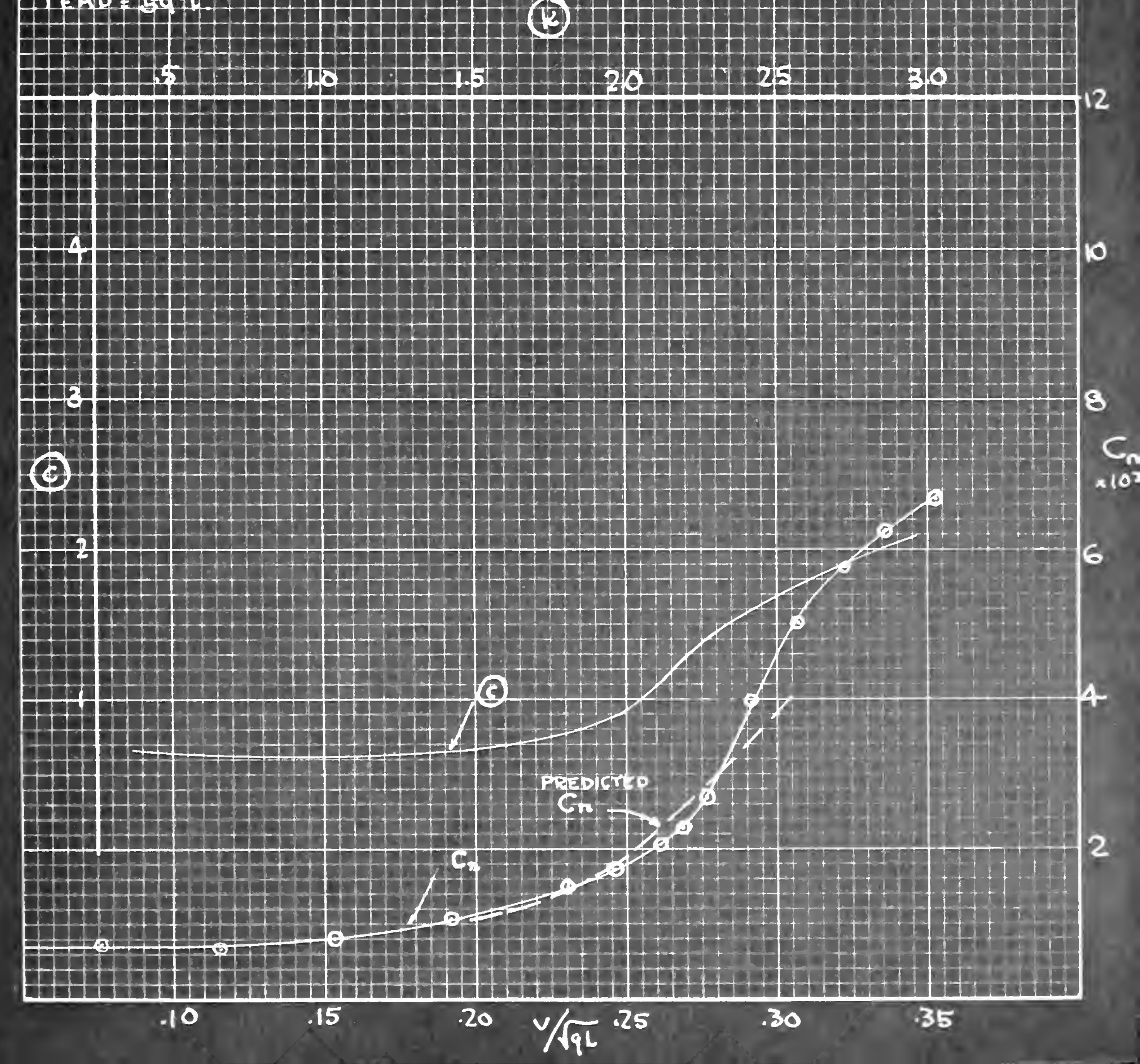


FIGURE XXXII

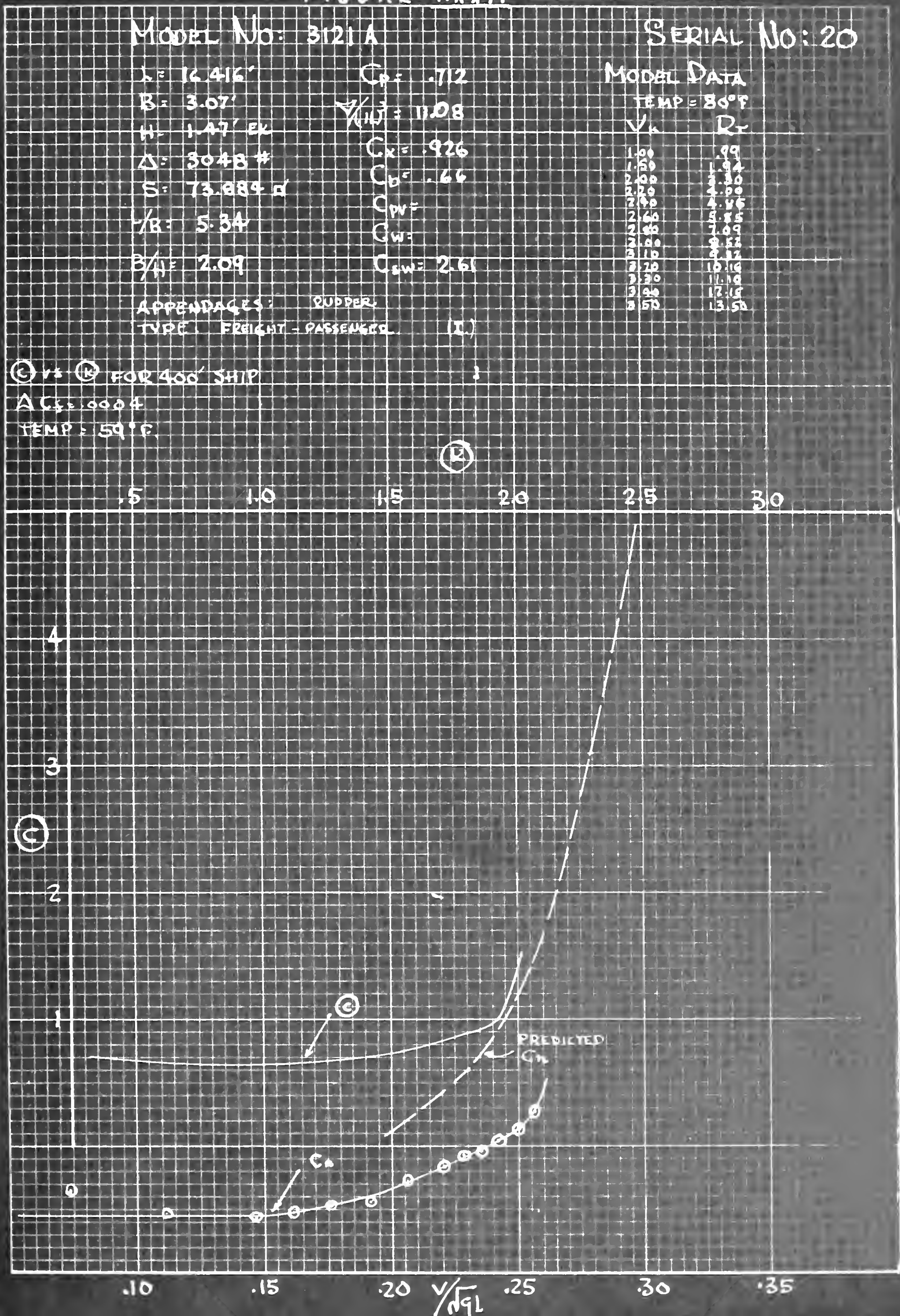


FIGURE XXXIII

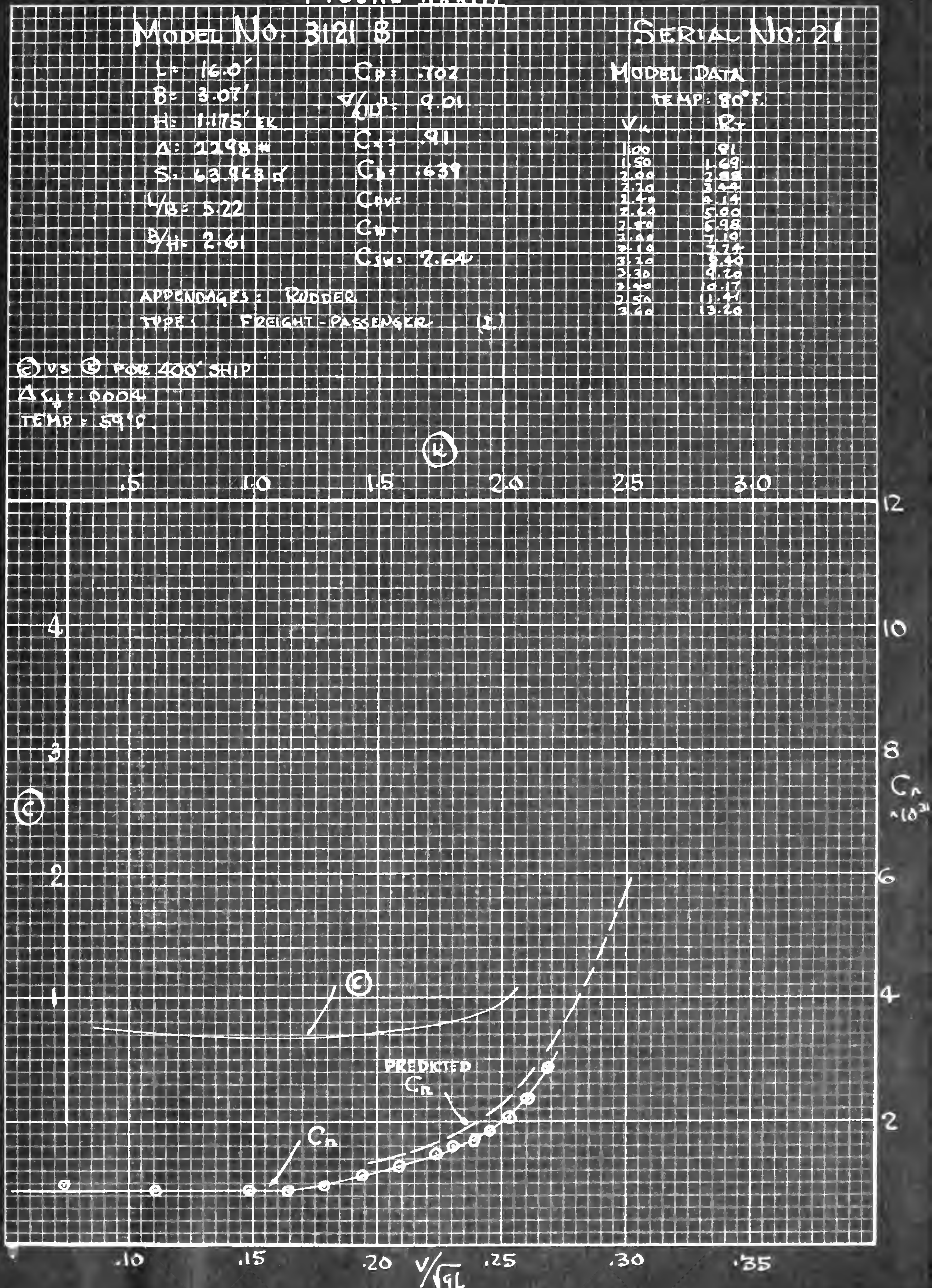


FIGURE XXXIV

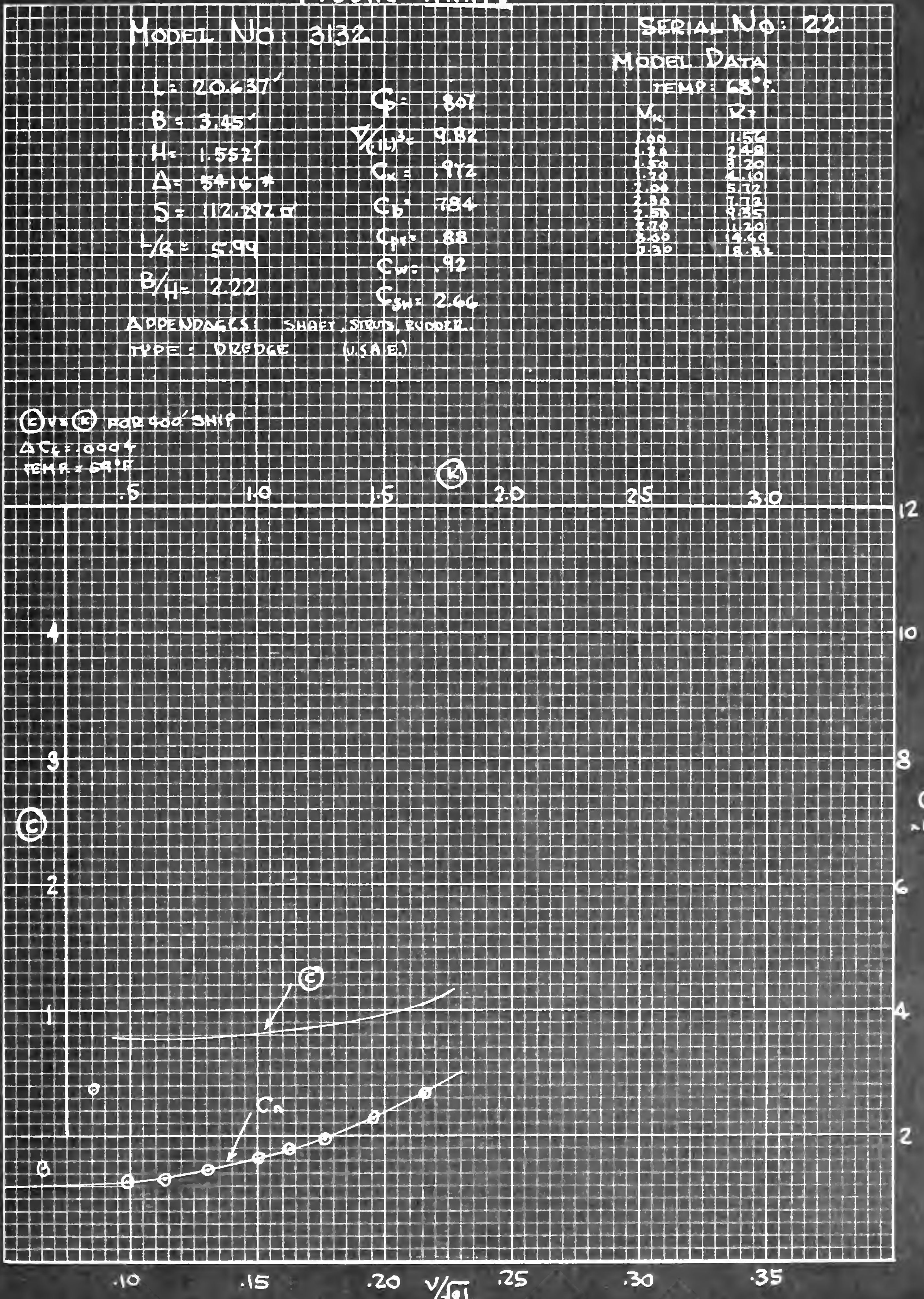


FIGURE XXXV

MODEL No: 3138 A

SERIAL No: 23

L = 14.7'
B = 3.428'
H = 1.553'
Δ = 2031 #
S = 65.867 □
L/B = 4.29
B/H = 2.21

C_p = .620
$\nabla/(L/10)^3$ = 13.30
C_x = .868
C_b = .540
C_{pv} = .707
C_w = .772
$C_{\oplus}$ = 2.605

APPENDAGES: — NONE

TYPE: HARBOR TUG. YT 119 (M)

MODEL DATA

TEMP: 68°F

V_L	R_T
1.00	.82
1.50	1.80
2.00	3.21
2.50	6.17
2.75	6.42
3.00	8.02
3.10	8.80
3.20	9.52
3.30	10.19
3.40	10.88
3.50	11.85
3.60	13.50
3.80	17.50
4.00	22.10
4.20	27.15

C vs K FOR 400' SHIP.
ΔC_f = .0004
TEMP = 59°F

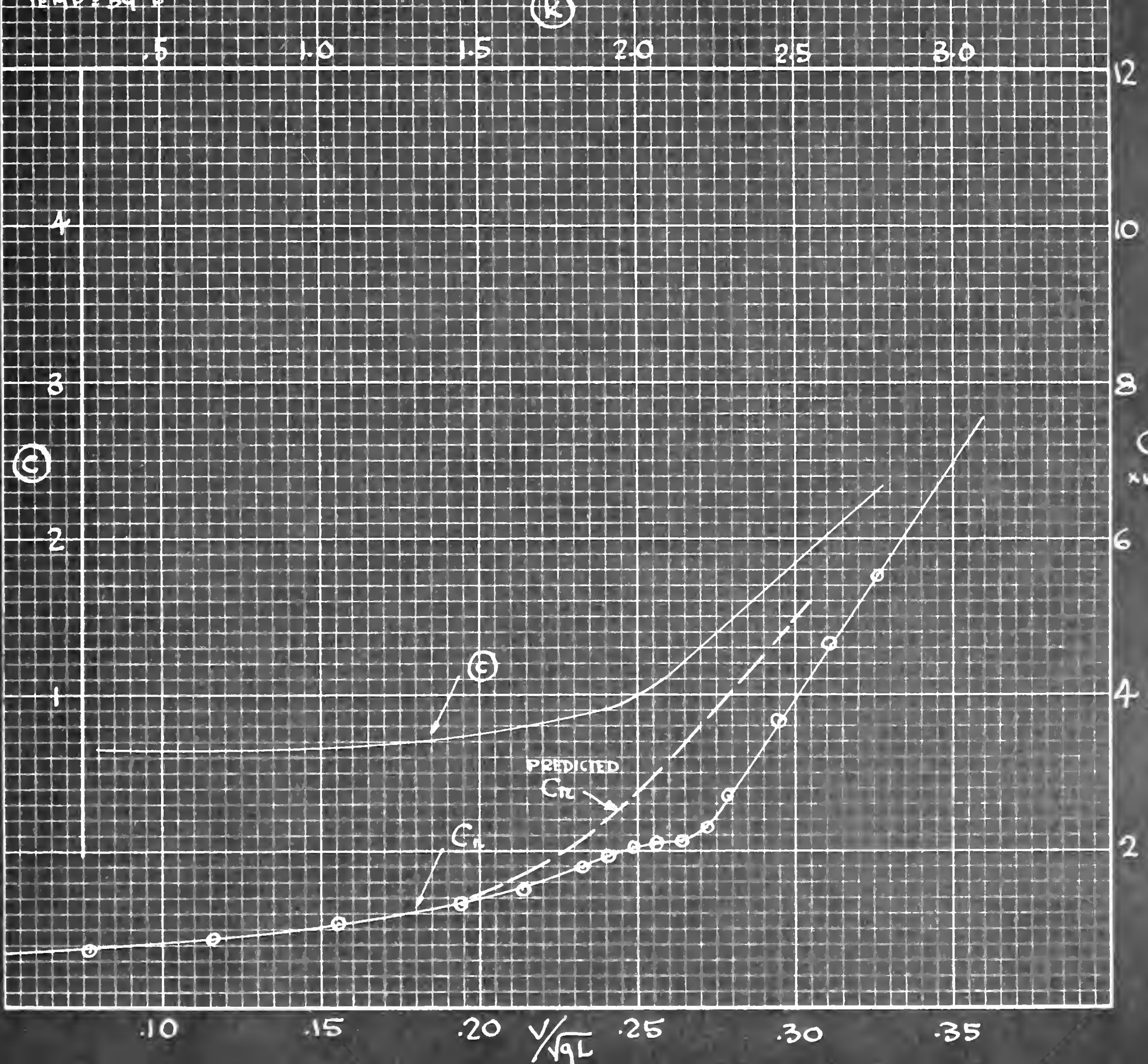


FIGURE XXXVI

MODEL NO: 3138 B

SERIAL NO: 24

$L = 14.2'$
$B = 3.428'$
$H = 1.352'$
$\Delta = 2153$ #
$S = 57.24$ □'
$L/B = 4.15$
$B/H = 2.54$

$C_p = .619$
$\nabla/(L/10)^3 = 12.10$
$C_x = .850$
$C_b = .524$
$C_{pv} =$
$C_w =$
$C_{sw} = 2.68$

APPENDAGES: NONE
TYPE: HARBOR TUG (N)

MODEL DATA
TEMP: 68° F

V_m	R_t
1.00	.69
1.50	1.56
2.00	2.81
2.50	4.46
2.75	5.48
3.00	6.92
3.10	7.60
3.20	8.24
3.30	8.82
3.40	9.44
3.50	10.20
3.60	11.25
3.80	15.07
4.00	18.50
4.20	21.90
4.30	23.55

C VS K FOR 400' SHIP
$\Delta C_f = .0004$
TEMP = 59° F

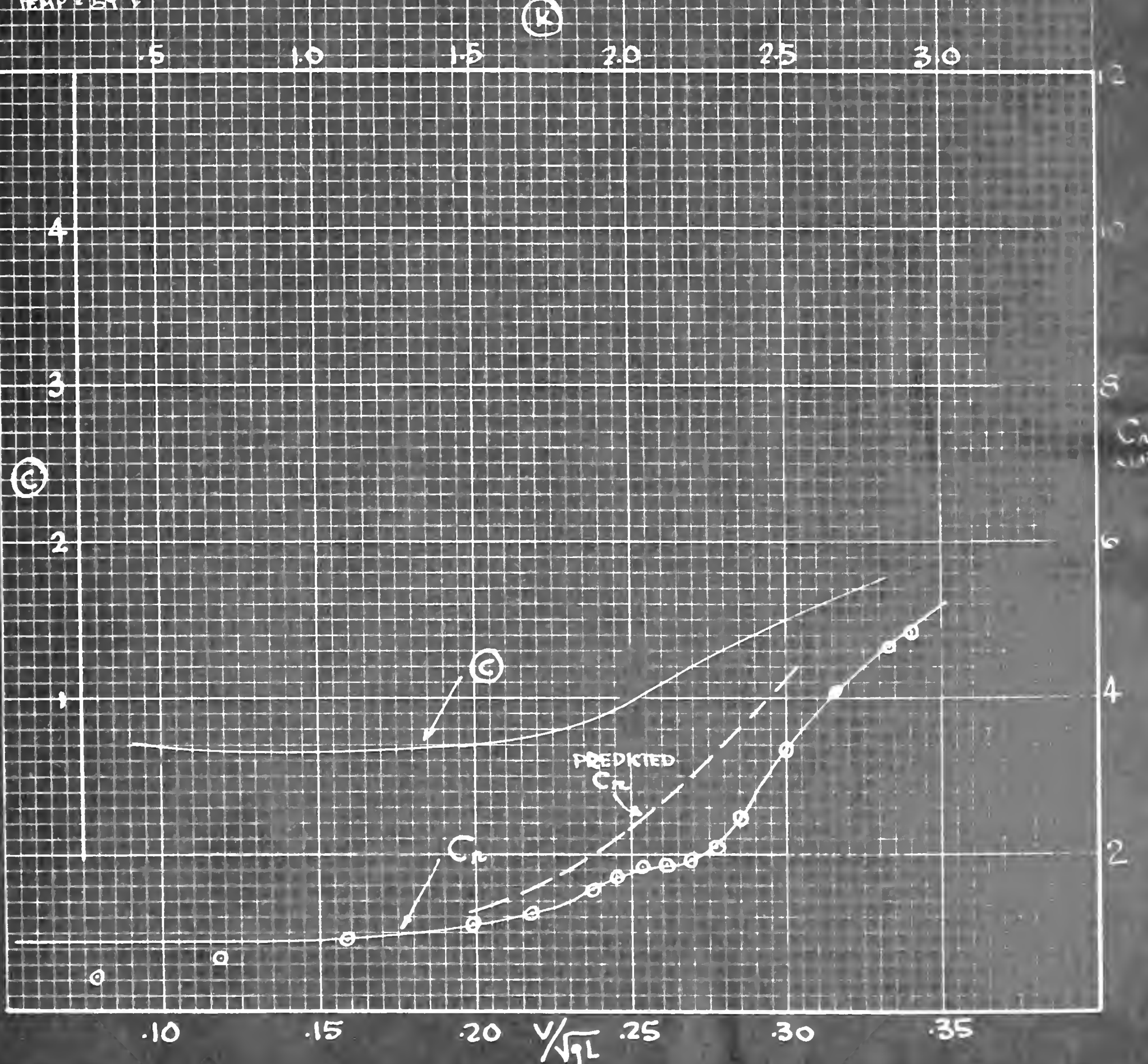


FIGURE XXXVII

MODEL No: 3175 — **SERIAL No: 25**

$L = 20.0$
$B = 3.735'$
$H = 1.332'$
$\Delta = 4801$ #
$S = 102.38$
$L/B = 5.36$
$B/H = 2.8$

$C_p = .778$
$\nabla/(.1L)^3 = 9.63$
$C_x = .996$
$C_b = .774$
$C_{vv} = .892$
$C_w = .865$
$C_{sw} = 2.61$

MODEL DATA

TEMP. 50°F.

V_m	R_T
1.00	1.42
1.50	3.06
2.00	5.30
2.30	7.10
2.50	8.61
2.70	10.40
3.00	13.62

APPENDAGES: NONE - OPENINGS IN BOTTOM, HOPPER DOORS.

TYPE: HOPPER DREDGE (USAE)

Ⓒ vs Ⓚ FOR 400' SHIP
$\Delta C_f = .0004$
TEMP = 59°F

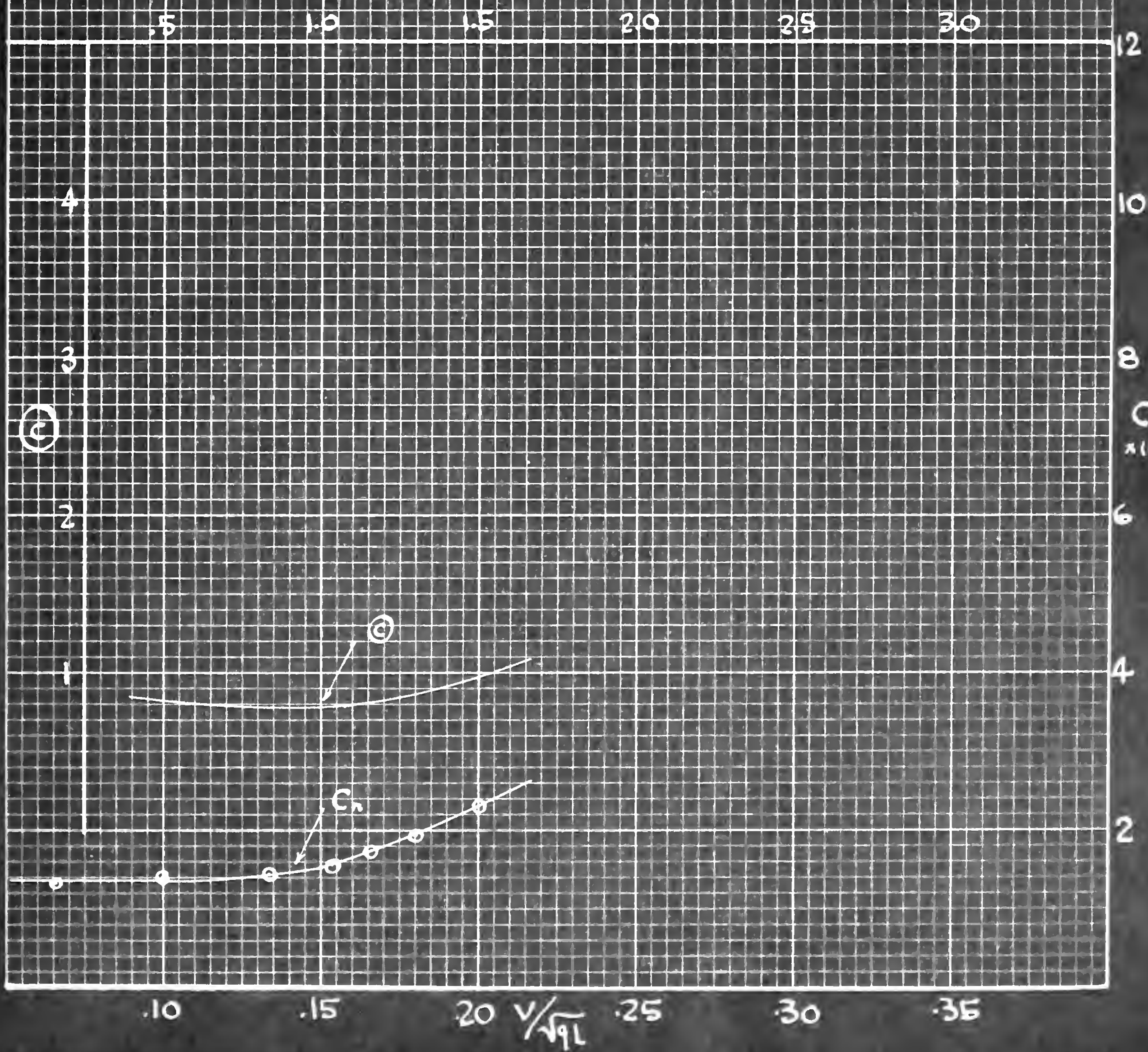


FIGURE XXXVIII

MODEL No: 3472

SERIAL No: 26

L = 20.0'
B = 3.734'
H = 1.333'
Δ = 4815 #
S = 104.027 □'
L/B = 5.36
B/H = 2.80

C_p = .788
$\nabla/(.1L)^3$ = 9.65
C_x = .984
C_b = .775
C_{pv} = .919
C_w = .842
C_{sw} = 2.65

MODEL DATA

TEMP: 56°F

V_K	R_T
1.00	1.58
1.50	3.47
2.00	6.00
2.30	7.88
2.50	9.26
2.70	10.80
3.00	14.10
3.10	15.70

APPENDAGES: BOSSING, HUB, FAIRWATER.

TYPE: SEA GOING HOPPER DREDGE (U.S.A.E.)

(C) vs (K) FOR 400' SHIP
ΔC_f = .0004
TEMP = 59° F.

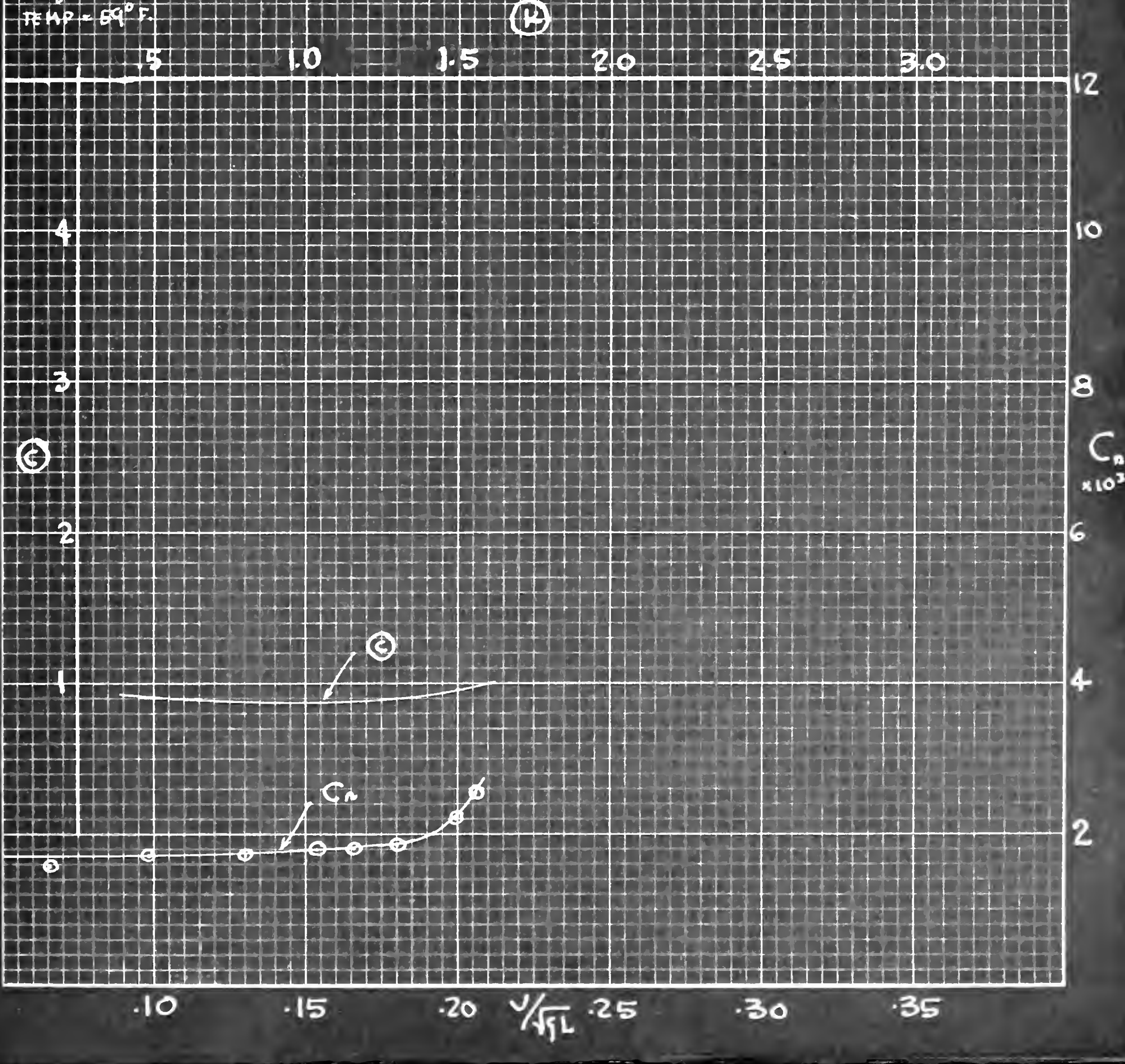


FIGURE XXXIX

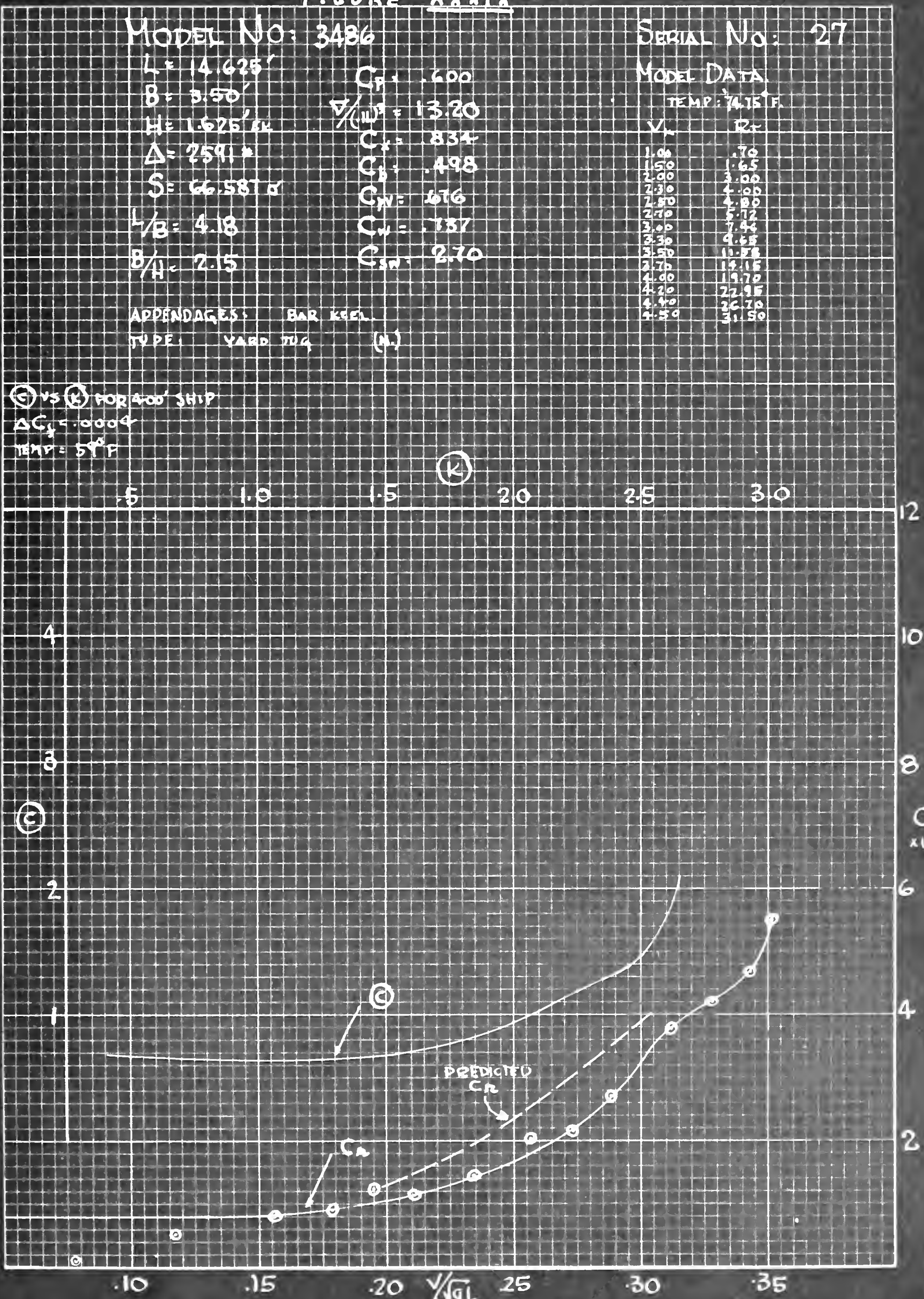


FIGURE XI

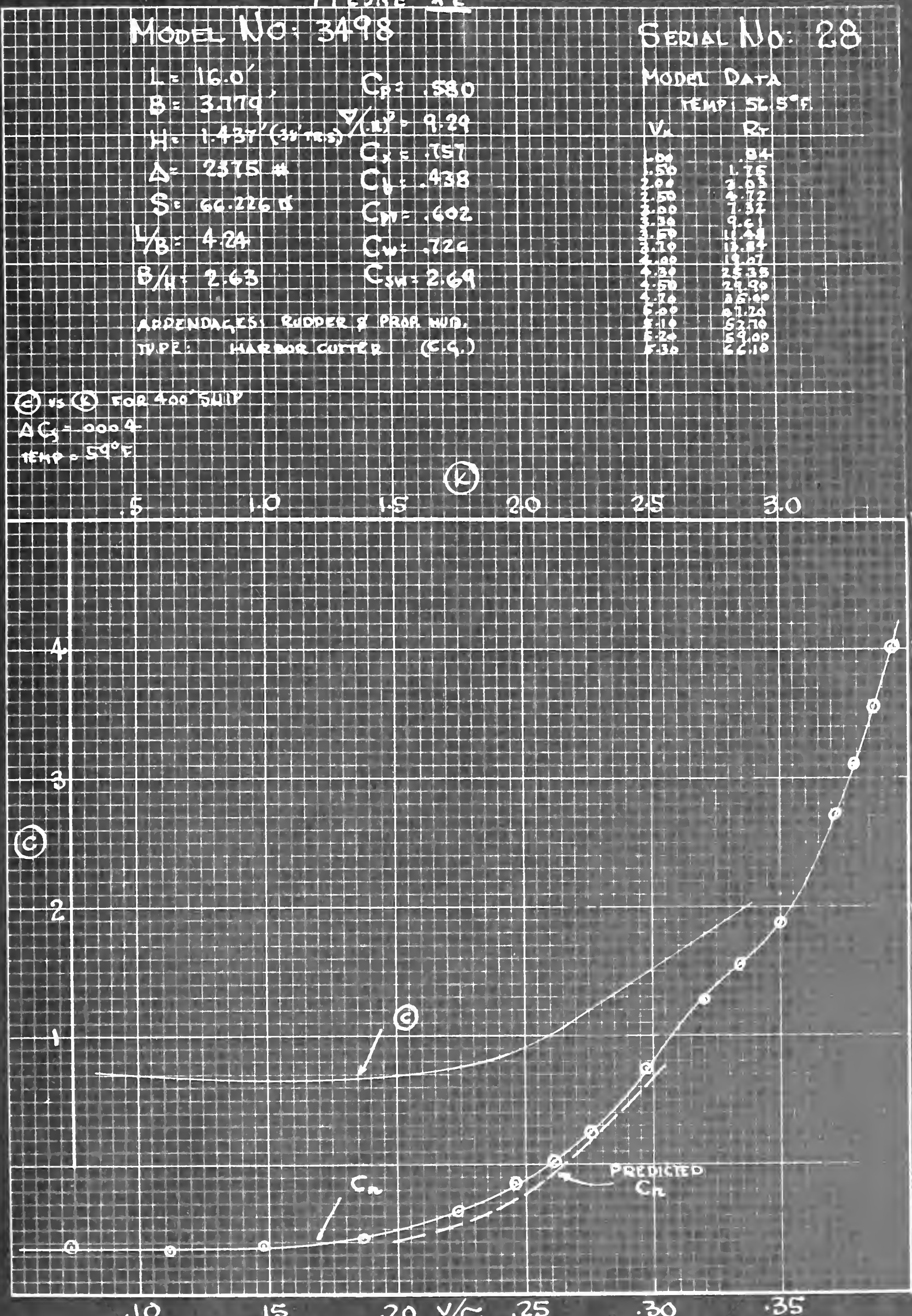

MODEL NO: 3498
SERIAL NO: 28
L = 16.0'
B = 3.779'
H = 1.437' (36" FRS)
Δ = 2375 #
S = 66.226 □'
L/B = 4.24
B/H = 2.63
Cp = .580
∇/(.1L)³ = 9.29
Cx = .757
Cb = .438
Cpv = .602
Cw = .726
Csw = 2.69
APPENDAGES: RUDDER & PROP. HUB.
TYPE: HARBOR CUTTER (C.G.)
MODEL DATA
TEMP: 52.5°F
Vk Rt
1.00 .84
1.50 1.76
2.00 3.03
2.50 4.72
3.00 7.32
3.20 9.61
3.50 11.48
3.70 13.84
4.00 19.07
4.30 25.38
4.50 29.90
4.70 36.00
5.00 47.20
5.10 52.70
5.20 59.00
5.30 66.10
© vs ® FOR 400' SHIP
ΔCf = .0004
TEMP = 59°F
®
.5 1.0 1.5 2.0 2.5 3.0
©
1 2 3 4
Cn ×10³
2 4 6 8 10 12
Cn
PREDICTED Cn
.10 .15 .20 V/√gL .25 .30 .35

FIGURE XLI

MODEL NO: 3685 — **SERIAL NO: 29**

L = 20.363'
B = 3.364'
H = 1.436' EN
Δ = 4520 #
S = 101.772 □'
L/B = 6.04
B/H = 2.35

C_P = .749
$\nabla/(.1L)^3$ = 8.62
C_x = .989
C_b = .741
C_{pv} = .908
C_w = .814
C_{sw} = 2.65

APPENDAGES: RUDDER
TYPE: (M)

MODEL DATA
TEMP. 72°F.

V_K	R_T
1.00	1.13
1.30	1.81
1.50	2.43
1.70	3.08
2.00	4.21
2.30	5.55
2.50	6.60
2.70	7.80
3.00	9.96
3.20	11.85
3.40	15.37
3.50	19.64
3.60	19.46
3.80	23.70
3.30	12.22

Ⓒ vs Ⓚ FOR 400' SHIP
ΔC_f = .0004
TEMP. 59°F.

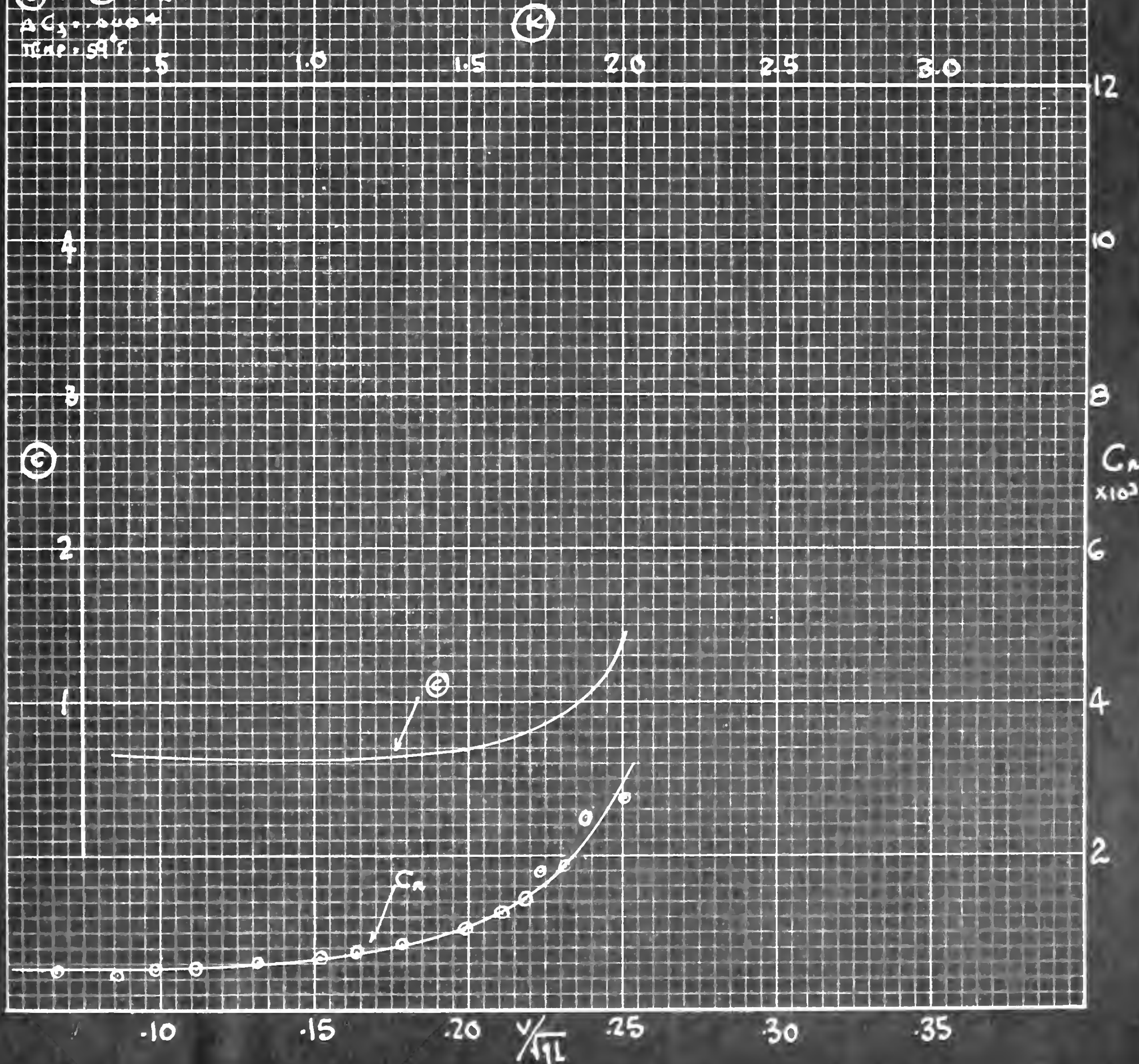


FIGURE XLII

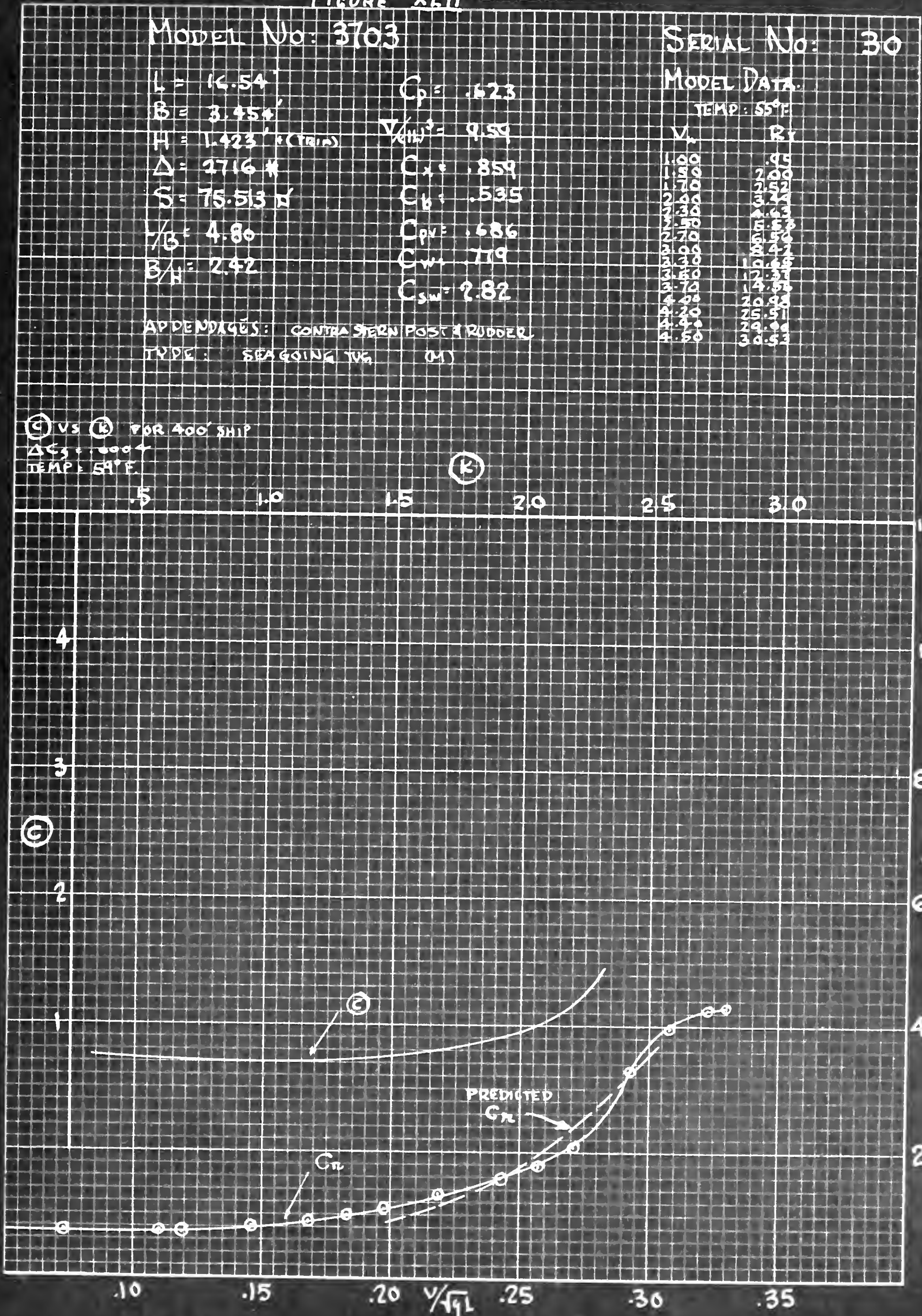

MODEL No: 3703
SERIAL No: 30
L = 16.54'
B = 3.454'
H = 1.423' (TRIM)
Δ = 2716 #
S = 75.513 □'
L/B = 4.80
B/H = 2.42
Cp = .623
V/(L/10)³ = 9.59
Cx = .859
Cb = .535
Cpv = .686
Cw = .779
Csw = 2.82
MODEL DATA
TEMP: 55°F
V Rt
1.00 .95
1.50 2.00
1.70 2.52
2.00 3.29
2.30 4.63
2.50 5.53
2.70 6.56
3.00 8.47
3.30 10.65
3.50 12.31
3.70 14.55
4.00 20.98
4.20 25.51
4.40 29.00
4.50 30.53
APPENDAGES: CONTRA STERN POST & RUDDER
TYPE: SEAGOING TUG (M)
© VS ® FOR 400' SHIP
ΔCs = .0004
TEMP = 59°F
®
.5
1.0
1.5
2.0
2.5
3.0
©
1
2
3
4
Cr x10³
2
4
6
8
10
12
©
PREDICTED Cr
Cr
.10
.15
.20
V/√gL
.25
.30
.35

FIGURE XLIII

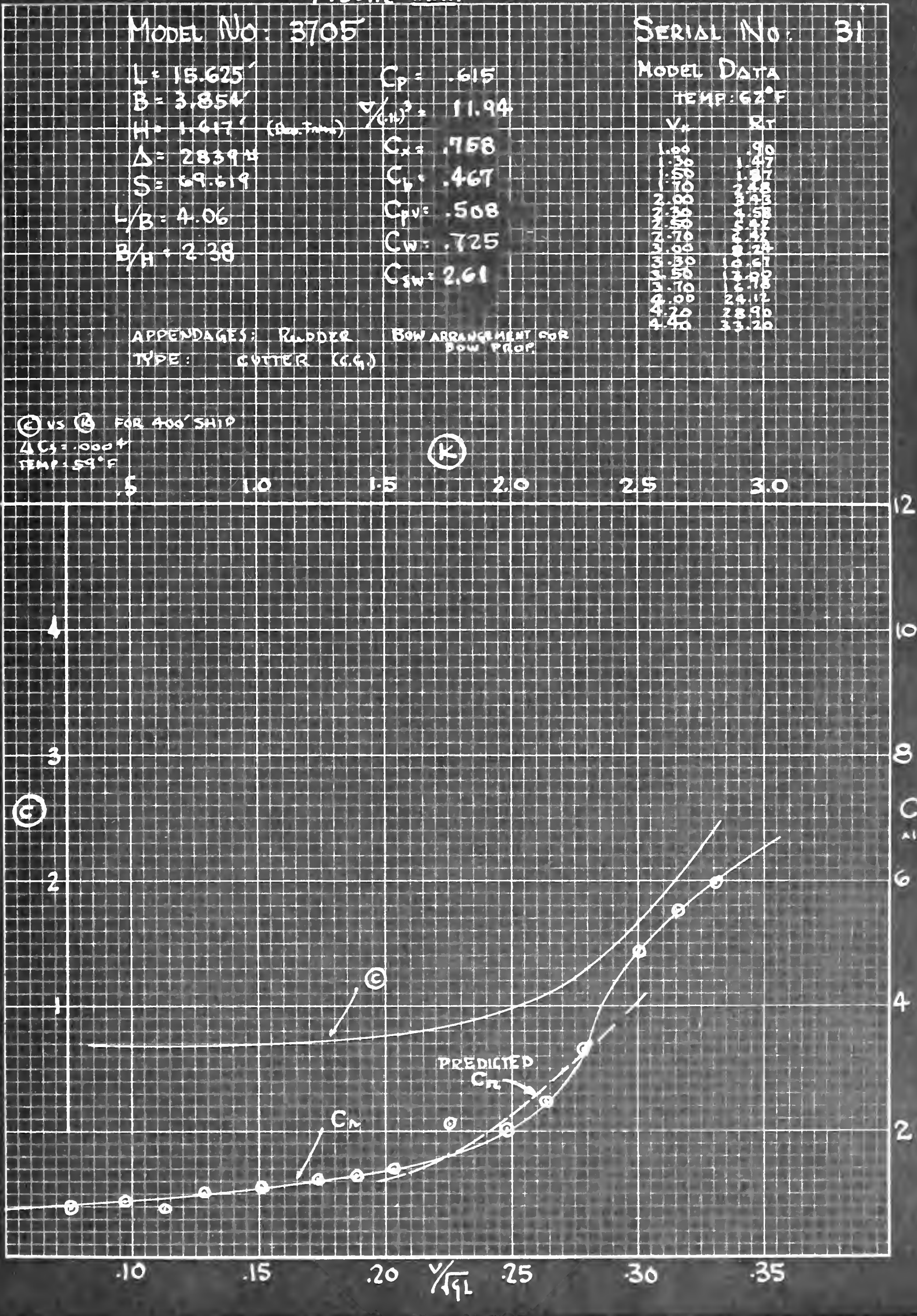


FIGURE XLIV

MODEL NO: 3714 — **SERIAL NO: 32**

L = 4.86
B =
H =
Δ = 64.86 #
S = 6.221 □'
L/B =
B/H = 2.12

C_p = .822
$\nabla/(.1L)^3$ = 9.05
C_x = .950
C_b = .781
C_{pv} =
C_w =
C_{sw} = 2.77

MODEL DATA

TEMP: 66°F

V_k	R_T
.3	.013
.4	.021
.5	.031
.6	.043
.7	.058
.8	.075
.9	.096
1.0	.122
1.1	.149
1.2	.180
1.3	.213
1.4	.250

APPENDAGES: NONE

TYPE: CONCRETE TANKER BARGE (M)

© vs Ⓚ FOR 400' SHIP
ΔCf = .0004
TEMP = 59°F

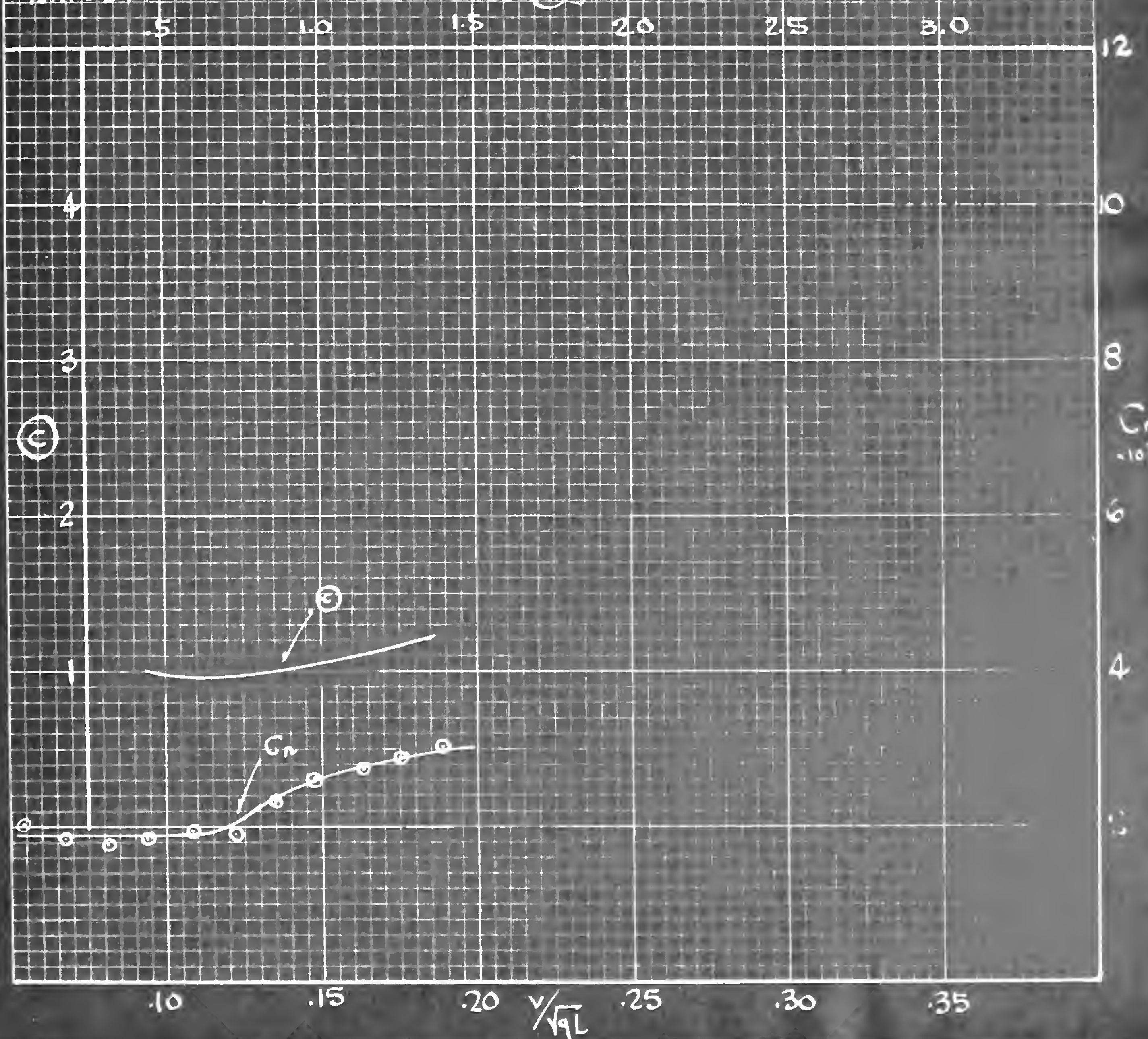


FIGURE XLV

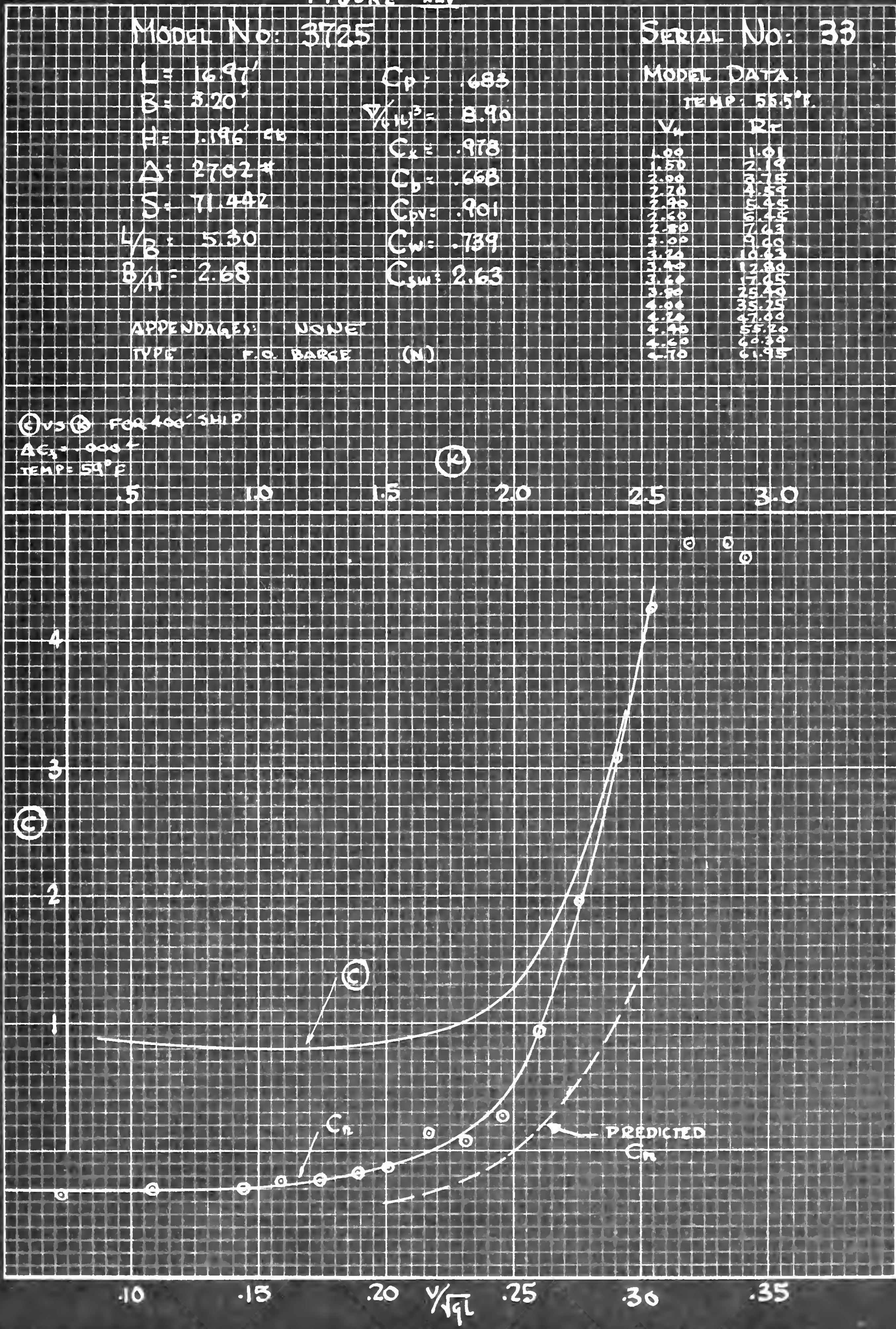

MODEL No: 3725
SERIAL No: 33
L = 16.97'
B = 3.20'
H = 1.196'
Δ = 2702 #
S = 71.442
L/B = 5.30
B/H = 2.68
Cp = .683
∇/(.1L)³ = 8.90
Cx = .978
Cb = .668
Cpv = .901
Cw = .739
Csw = 2.63
MODEL DATA
TEMP: 55.5°F.
Vk Rt
1.00 1.01
1.50 2.19
2.00 3.75
2.20 4.59
2.40 5.45
2.60 6.45
2.80 7.63
3.00 9.00
3.20 10.63
3.40 12.80
3.60 17.65
3.80 25.40
4.00 35.25
4.20 47.00
4.40 55.20
4.60 60.30
4.70 61.95
APPENDAGES: NONE
TYPE F.O. BARGE (N)
C VS K FOR 400' SHIP
ΔCf = .0004
TEMP = 59°F
K
.5
1.0
1.5
2.0
2.5
3.0
C
4
3
2
1
12
10
8
6
4
2
Cr ×10³
Cr
PREDICTED Cr
.10
.15
.20
.25
.30
.35
V/√gL

FIGURE XLVI

MODEL No: 3745

SERIAL No: 34

$L = 20.335'$

$B = 3.088'$

$H = 1.50'$ EK

$\Delta = 4469$ #

$S = 101.788$ ☐'

$L/B = 6.58$

$B/H = 2.06$

$C_p = .770$

$\nabla/(.1L)^3 = 8.56$

$C_x = .990$

$C_b = .762$

$C_{pv} = .913$

$C_w = .832$

$C_{sw} = 2.66$

MODEL DATA.

TEMP: 57°F

V_k	R_T
1.0	1.20
1.5	2.55
2.0	4.33
2.2	5.19
2.4	6.14
2.6	7.21
2.8	8.46
3.0	9.85
3.1	10.63

APPENDAGES: NONE

TYPE: CONCRETE BARGE (M)

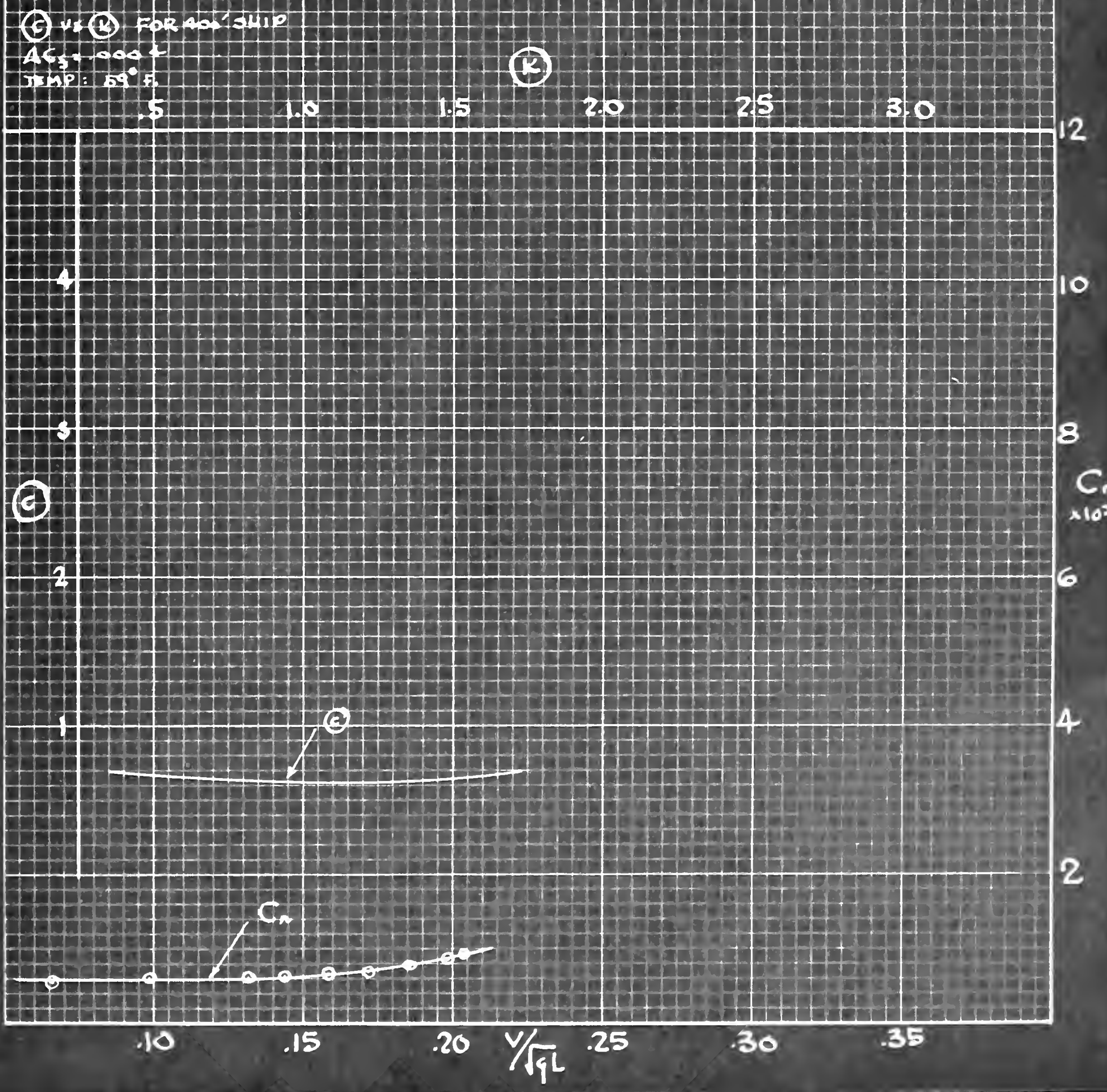


FIGURE XLVII

MODEL No: 3755 | SERIAL No: 35

L = 16.352'
B = 3.506'
H = 1.290' (DES. DRAG)
Δ = 2330 #
S = 75.28 □'
L/B = 4.66
B/H = 2.72

C_p = .675
$\nabla/(.1L)^3$ = 8.50
C_x = .749
C_b = .505
C_{pv} = .636
C_w = .793
C_{sw} = 3.06

MODEL DATA.
TEMP: 67°F

V_m	R_T
1.0	1.02
1.5	2.17
2.0	3.83
2.5	6.09
3.0	9.21
3.2	11.02
3.4	12.97
3.6	15.14
3.8	18.48
4.0	23.30
4.1	26.18
4.2	29.14
4.4	34.00
4.6	38.16
4.8	42.14
4.9	44.12

APPENDAGES: LOG. KEEL, BILGE KEELS
TYPE: COSTAL MINE SWEEP (N)

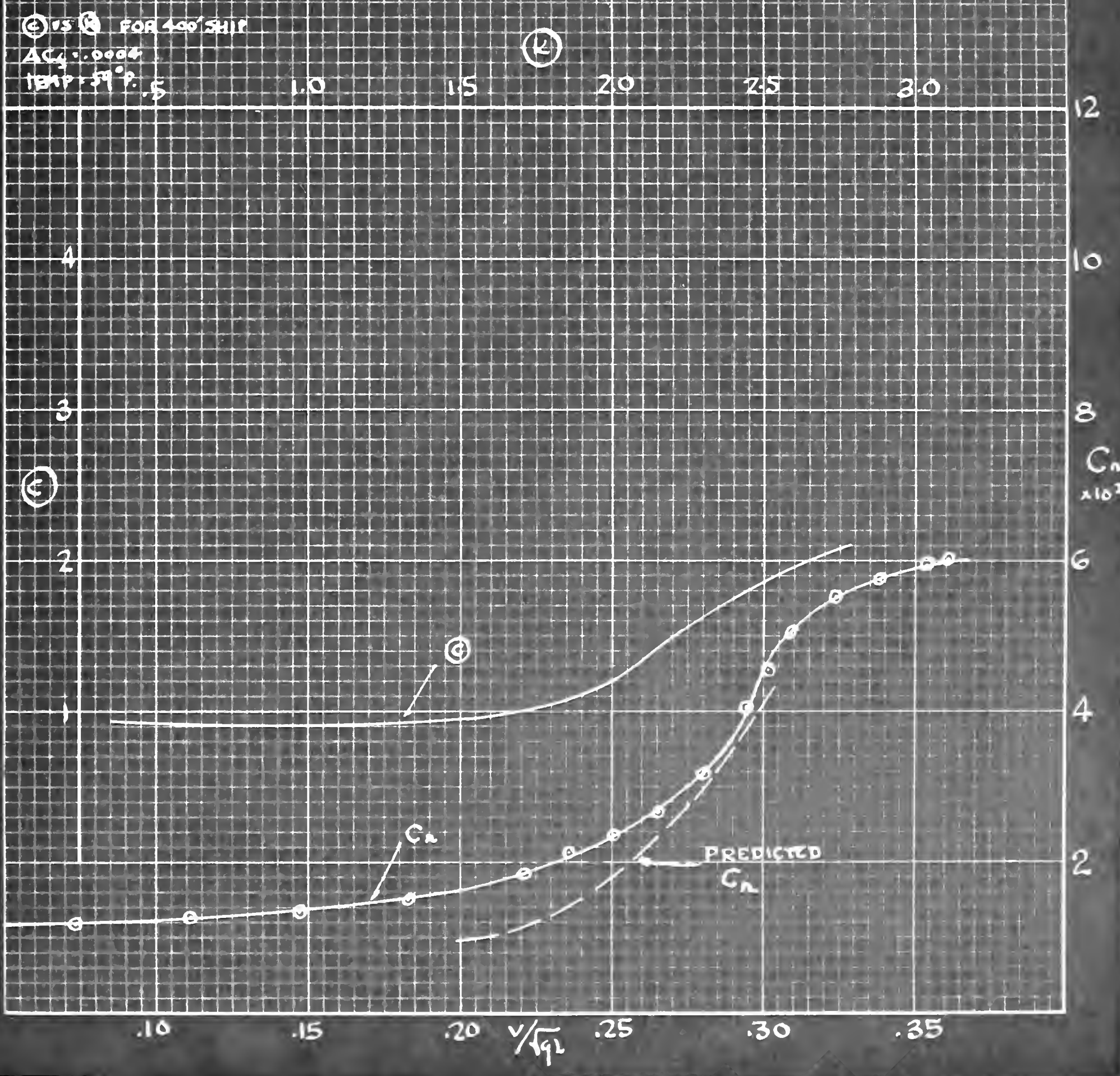


FIGURE XLVIII

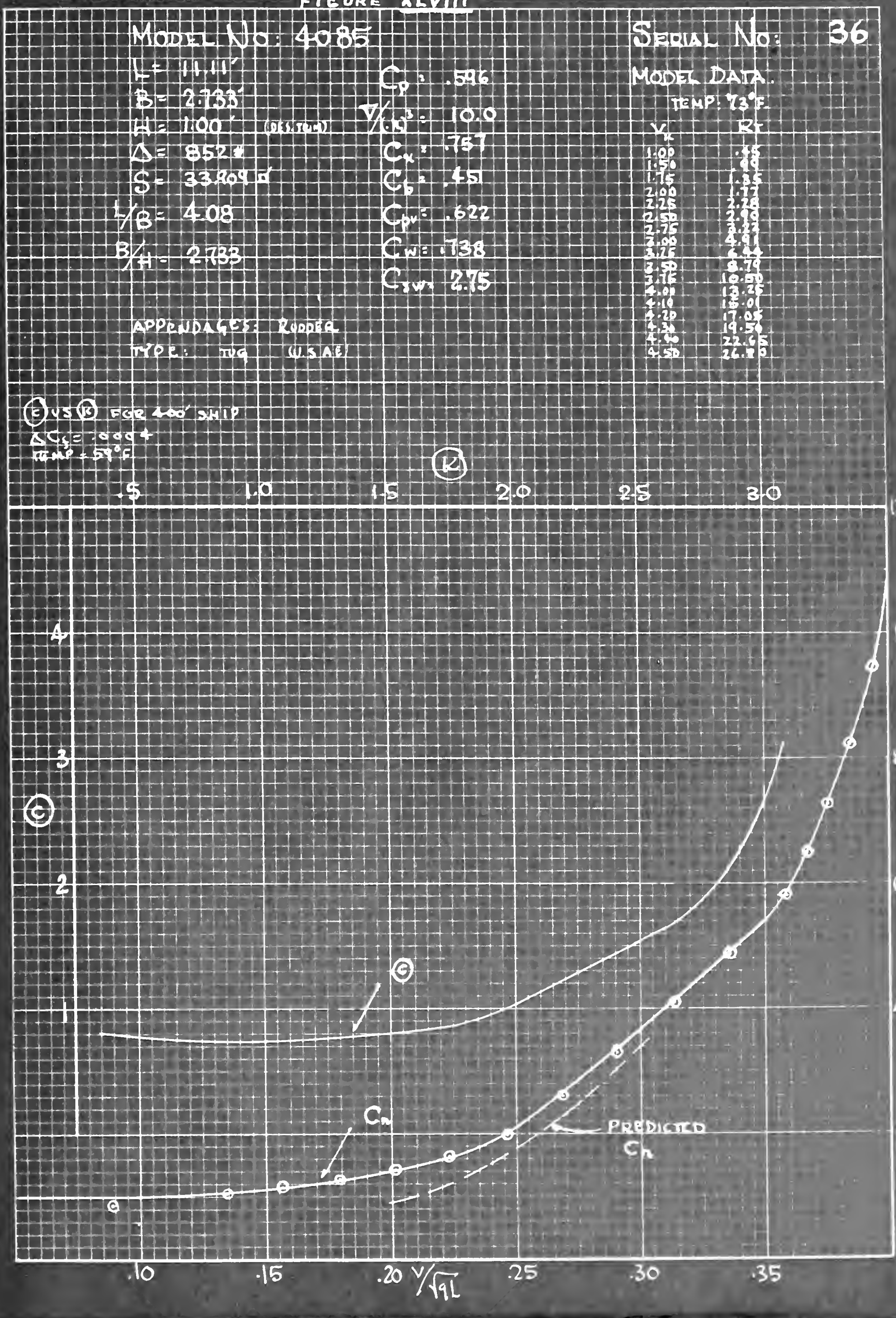


FIGURE XLIX

MODEL NO: 4086

SERIAL NO: 37

L = 11.11'
B = 2.620'
H = 1.072' (DES. TRIM)
Δ = 1048 #
S = 37.226 □'
L/B = 4.24
B/H = 2.442

C_p = .615
$\nabla/(.1L)^3$ = 12.23
C_x = .876
C_b = .538
C_{pv} = .711
C_w = .758
C_{sw} = 2.73

APPENDAGES: RUDDER
TYPE: TUG (USAE)

MODEL DATA
TEMP: 64°F

V_K	R_T
1.000	.60
1.405	1.04
1.755	1.48
2.000	1.90
2.300	2.58
2.600	3.39
2.800	4.05
3.005	5.24
3.203	6.90
3.410	8.92
3.600	10.60
3.800	12.35
3.905	13.50
4.000	14.85
4.105	16.85
4.210	19.46
4.300	22.60
4.400	22.65

Ⓒ VS Ⓚ FOR 400' SHIP
ΔC_f = .0004
TEMP: 59°F

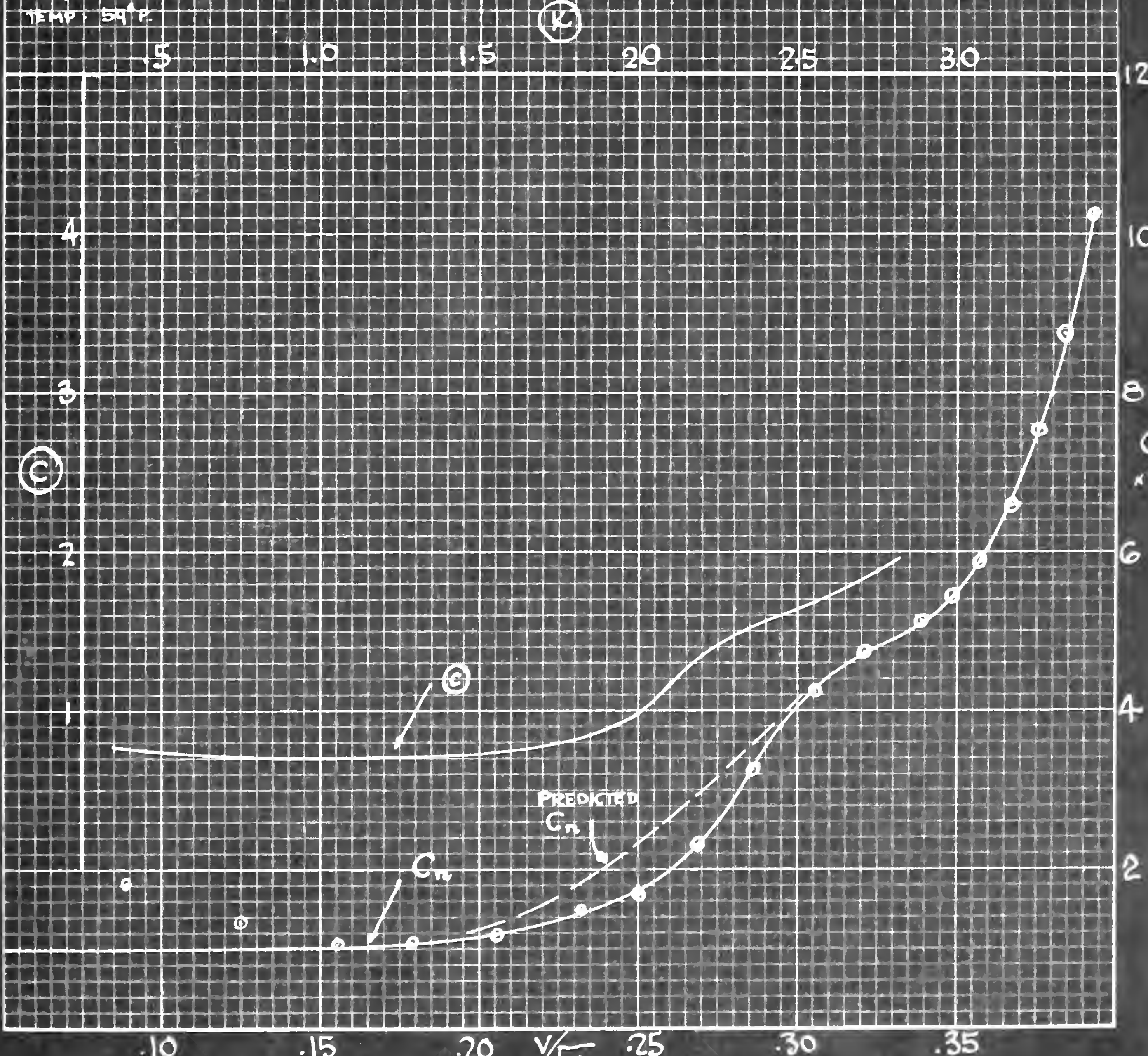


FIGURE I

MODEL NO: 4087

SERIAL NO: 38

L = 11.11′	C_P = .583
B = 3.40′	$\nabla/(L/10)^3$ = 15.17
H = 1.18′ (DES. TRIM)	C_x = .801
Δ = 1297 #	C_B = .467
S = 46.5 □′	C_{PV} = .626
L/B = 3.27	C_W = .745
B/H = 2.88	C_{SW} = 3.06

MODEL DATA

TEMP: 73°F

V_M	R_T	
1.01	.598	CORRECTED FOR TURBULENT FLOW.
1.404	1.112	
1.80	1.867	
2.205	2.750	
2.50	3.680	
2.75	4.70	
3.00	5.92	
3.20	7.17	
3.41	8.78	
3.60	10.52	
3.70	11.70	
3.80	12.85	
3.89	14.20	
4.00	16.10	
4.12	19.00	
4.21	21.41	
4.30	25.37	
4.40	28.85	

APPENDAGES: RUDDER. (SAND STRIP TURB. IND.)

TYPE: TUG (USAF)

C VS K FOR 400′ SHIP

ΔC_f = .0004

TEMP: 59°F.

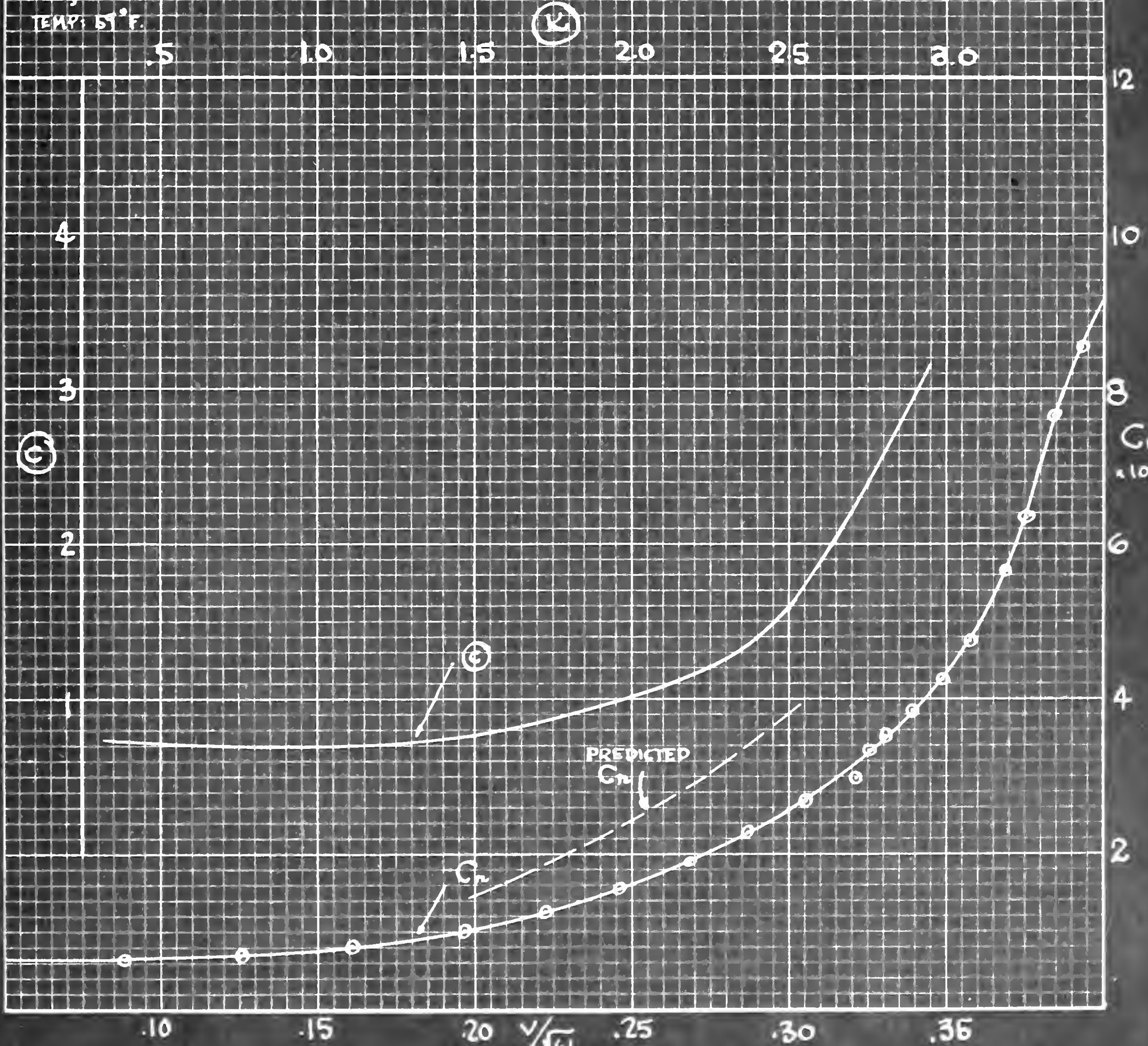


FIGURE II

MODEL NO: 4088 — **SERIAL NO: 39**

L = 11.11′
B = 2.99′
H = 1.278′
Δ = 1441 #
S = 44.5 □′
L/B = 3.72
B/H = 2.34

C_P = .623
$\nabla/(.1L)^3$ = 16.89
C_X = .873
C_B = .544
C_{PV} = .701
C_W = .776
C_{SW} = 2.78

MODEL DATA
TEMP. 75°F

V_L	R_T
1.00	.58
1.50	1.33
1.75	1.82
2.00	2.40
2.25	3.07
2.50	3.88
2.75	5.88
3.00	6.39
3.25	8.98
3.50	11.74
3.75	14.40
4.00	17.82
4.10	19.78
4.20	22.35
4.30	25.99
4.40	30.70
4.50	36.65

APPENDAGES: RUDDER (SAND STRIP TURB. IND.)
TYPE: TUG (USAE)

© vs Ⓚ FOR 400′ SHIP
ΔC_f = .0004
TEMP = 59°F.

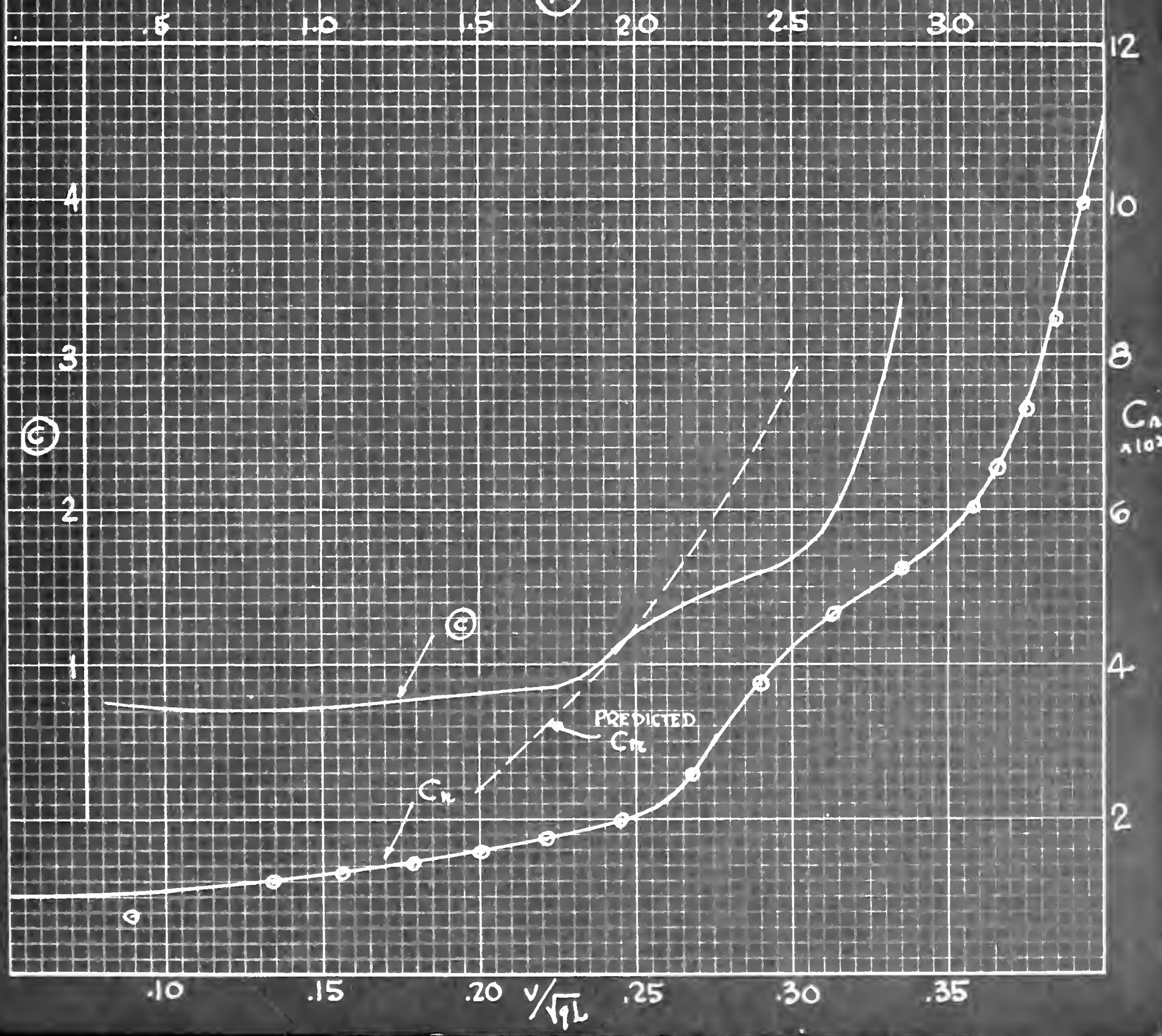


FIGURE LII

MODEL NO: 4690 — **SERIAL NO: 40**

L = 11.11′
B = 2.485′
H = .917′
Δ = 880#
S = 35.394□′
L/B = 4.47
B/H = 2.71

C_p = .677
$\nabla/(.10L)^3$ = 10.30
C_x = .821
C_b = .556
C_{pv} = .717
C_w = .776
C_{sw} = 2.84

APPENDAGES: RUDDER (SAND STRIP TURB IND.)
TYPE: TUG (USAE)

MODEL DATA
TEMP: 67°F

V_k	R_T	
1.00	.52	CORRECTED FOR TURBULENT FLOW
1.50	1.08	
1.75	1.44	
2.00	1.80	
2.25	2.46	
2.50	3.18	
2.75	4.08	
3.00	5.38	
3.25	7.81	
3.50	12.71	
3.75	15.88	
4.00	17.69	
4.10	18.86	
4.20	20.20	
4.30	21.75	
4.40	23.48	
4.50	25.45	

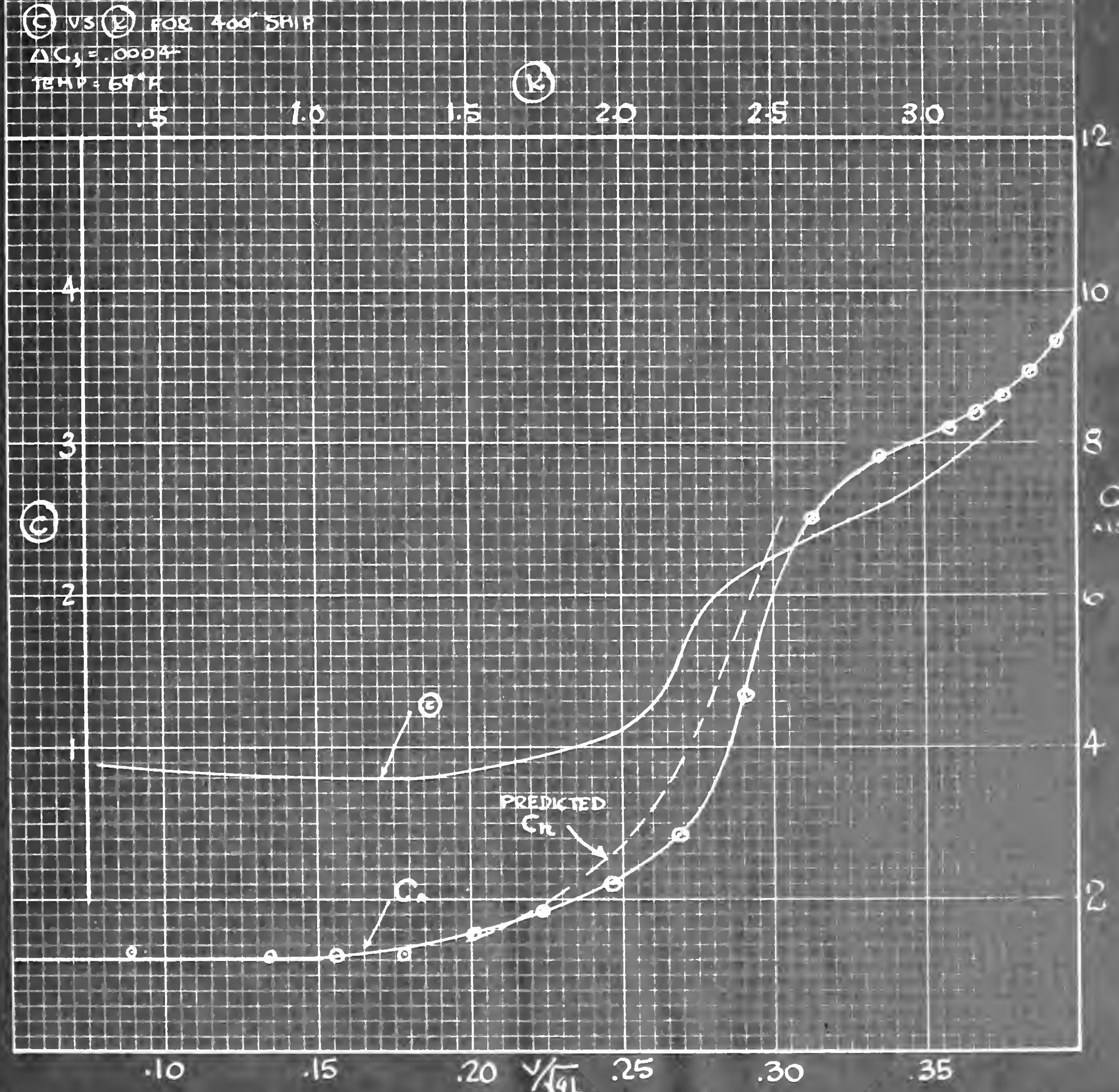


FIGURE LIII

MODEL NO: 4091 SERIAL NO: 41

L = 11.11'
B = 2.92'
H = 1.097'
Δ = 1039 #
S = 37.64 □'
L/B = 3.81
B/H = 2.665

C_P = .586
$\nabla/(L/10)^3$ = 12.15
C_X = .794
C_∇ = .465
C_W = .648
C_{W} = .717
C_{SW} = 2.77

MODEL DATA
TEMP: 62°F

V_m	R_T
1.00	.56
1.50	1.16
1.75	1.57
2.00	2.08
2.25	2.65
2.50	3.38
2.75	4.24
3.00	5.49
3.25	7.18
3.50	9.14
3.75	11.35
4.00	14.79
4.10	16.17
4.20	17.70
4.30	20.80
4.40	25.45
4.50	31.80

APPENDAGES: RODDED (TURBULENCE SAND STRIP)
TYPE: TUG (USBAE)

Ⓒ VS Ⓚ FOR 400' SHIP
ΔC_f = .0004
TEMP = 59°F.

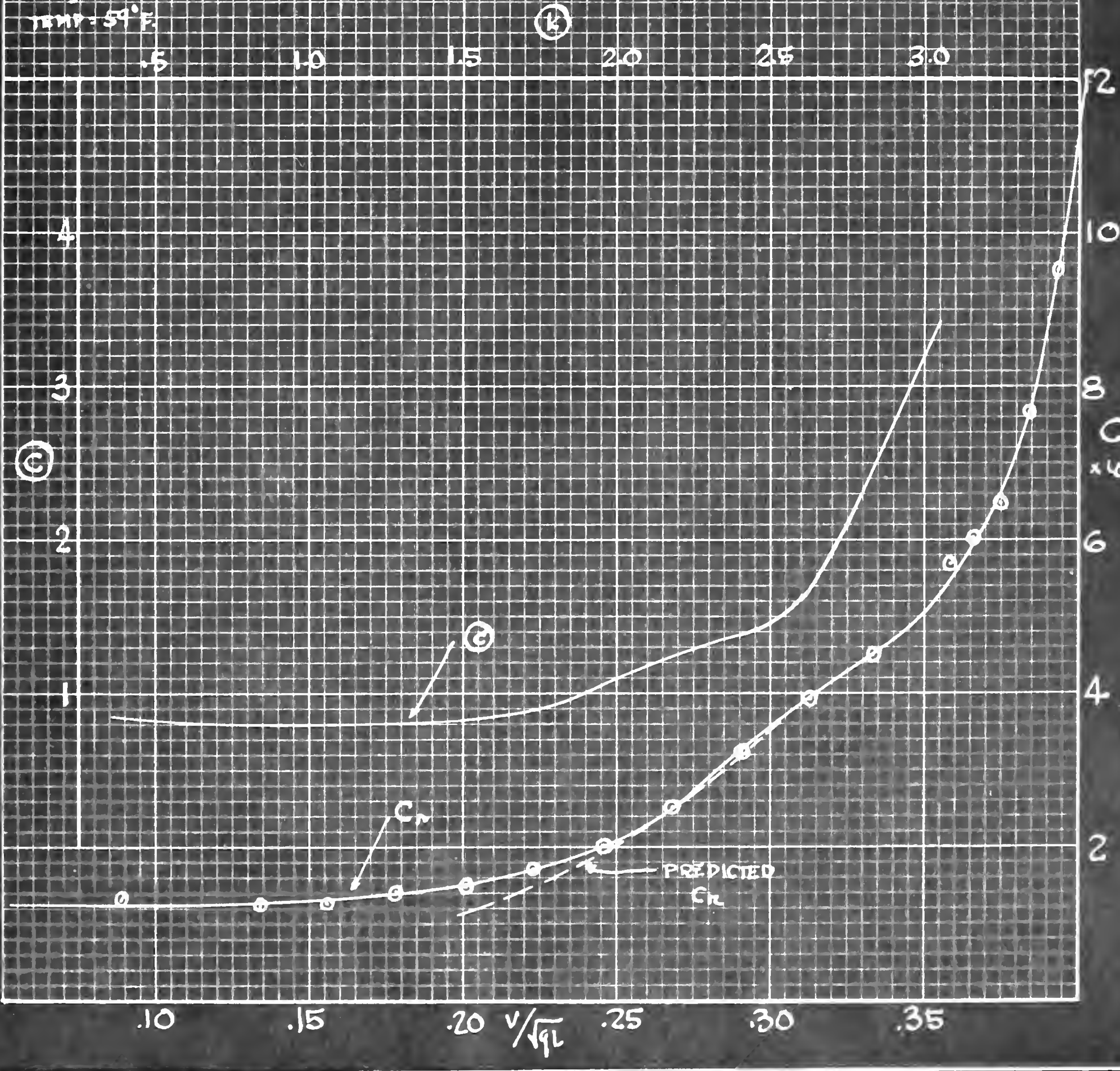


FIGURE LIV

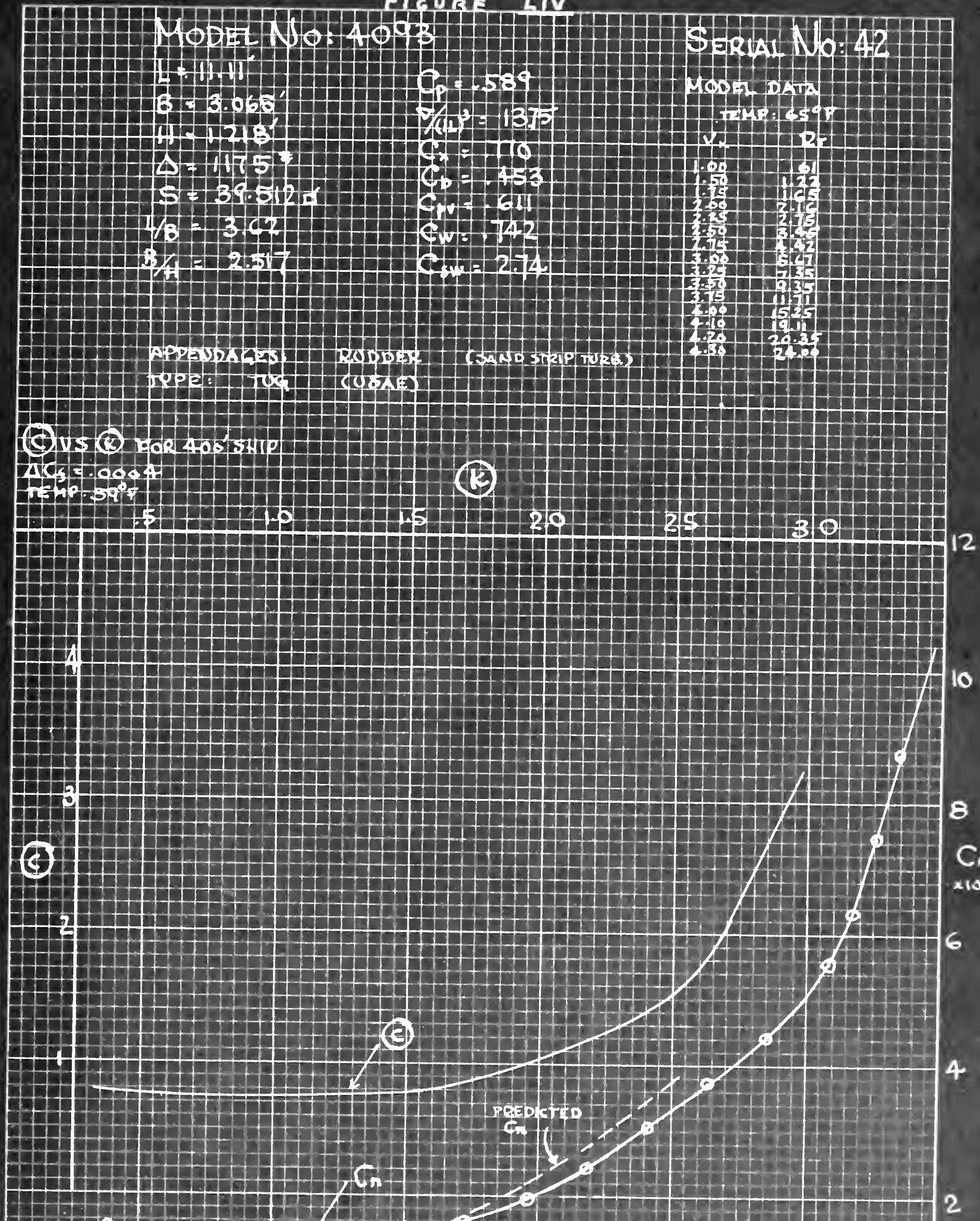

MODEL No: 4093
SERIAL No: 42
L = 11.11'
B = 3.068'
H = 1.218'
Δ = 1175#
S = 39.512 □'
L/B = 3.62
B/H = 2.517
Cp = .589
∇/(L)³ = 1375
Cx = .770
Cb = .453
Cpv = .611
Cw = .742
Csw = 2.74
MODEL DATA
TEMP: 65°F
V | Rf
1.00 | .61
1.50 | 1.22
1.75 | 1.65
2.00 | 2.16
2.25 | 2.75
2.50 | 3.46
2.75 | 4.42
3.00 | 6.47
3.25 | 7.35
3.50 | 9.35
3.75 | 11.71
4.00 | 15.25
4.10 | 19.11
4.20 | 20.35
4.30 | 24.00
APPENDAGES: RUDDER (SAND STRIP TURB.)
TYPE: TUG (UDAE)
C VS K FOR 400' SHIP
ΔCf = .0004
TEMP. 59°F
K
.5
1.0
1.5
2.0
2.5
3.0
12
10
8
Cn
x10³
6
4
2
4
3
C
2
1
C
PREDICTED
Cn
Cn
.10
.15
.20
V/√gL
.25
.30
.35

FIGURE IV

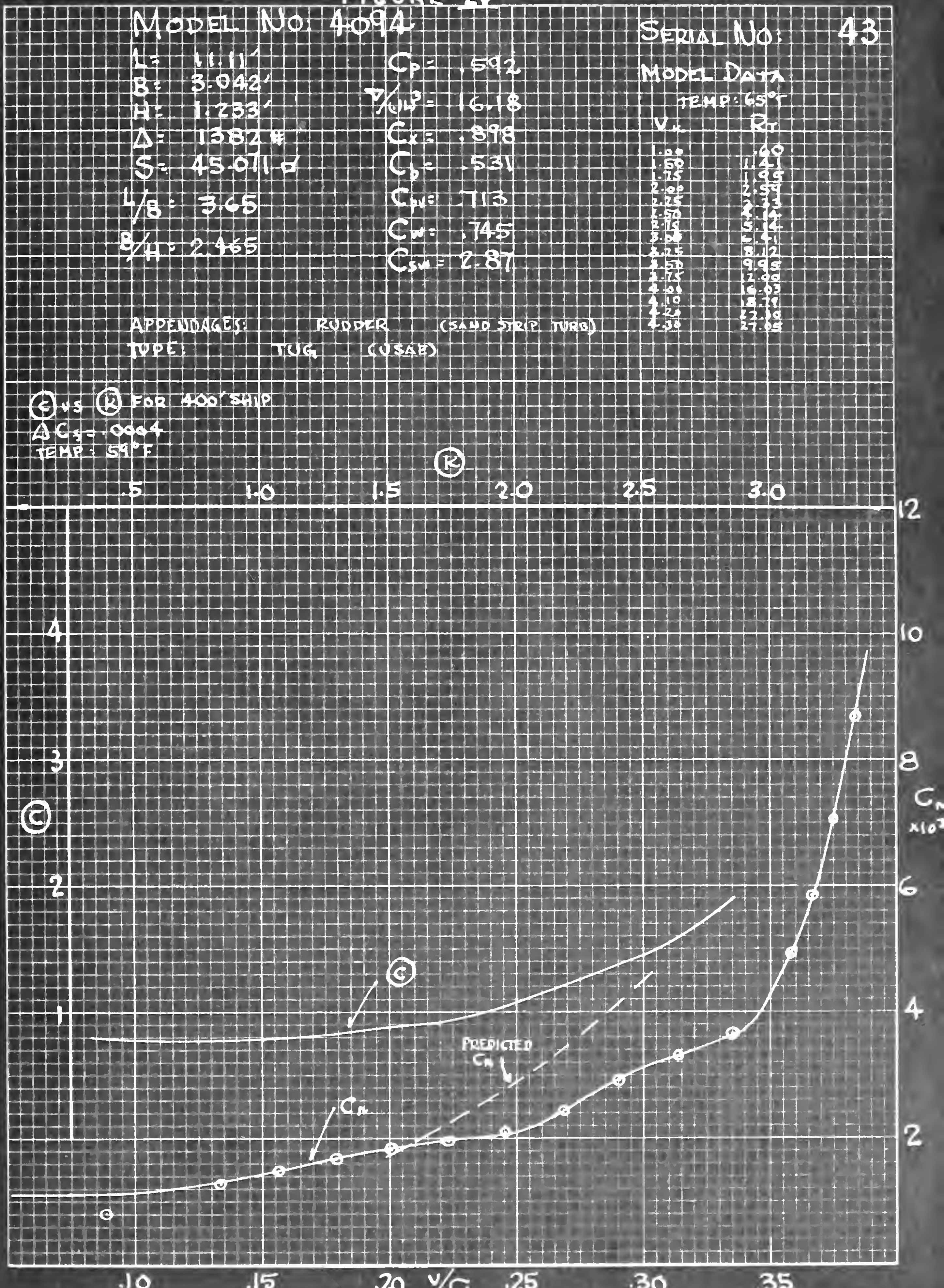
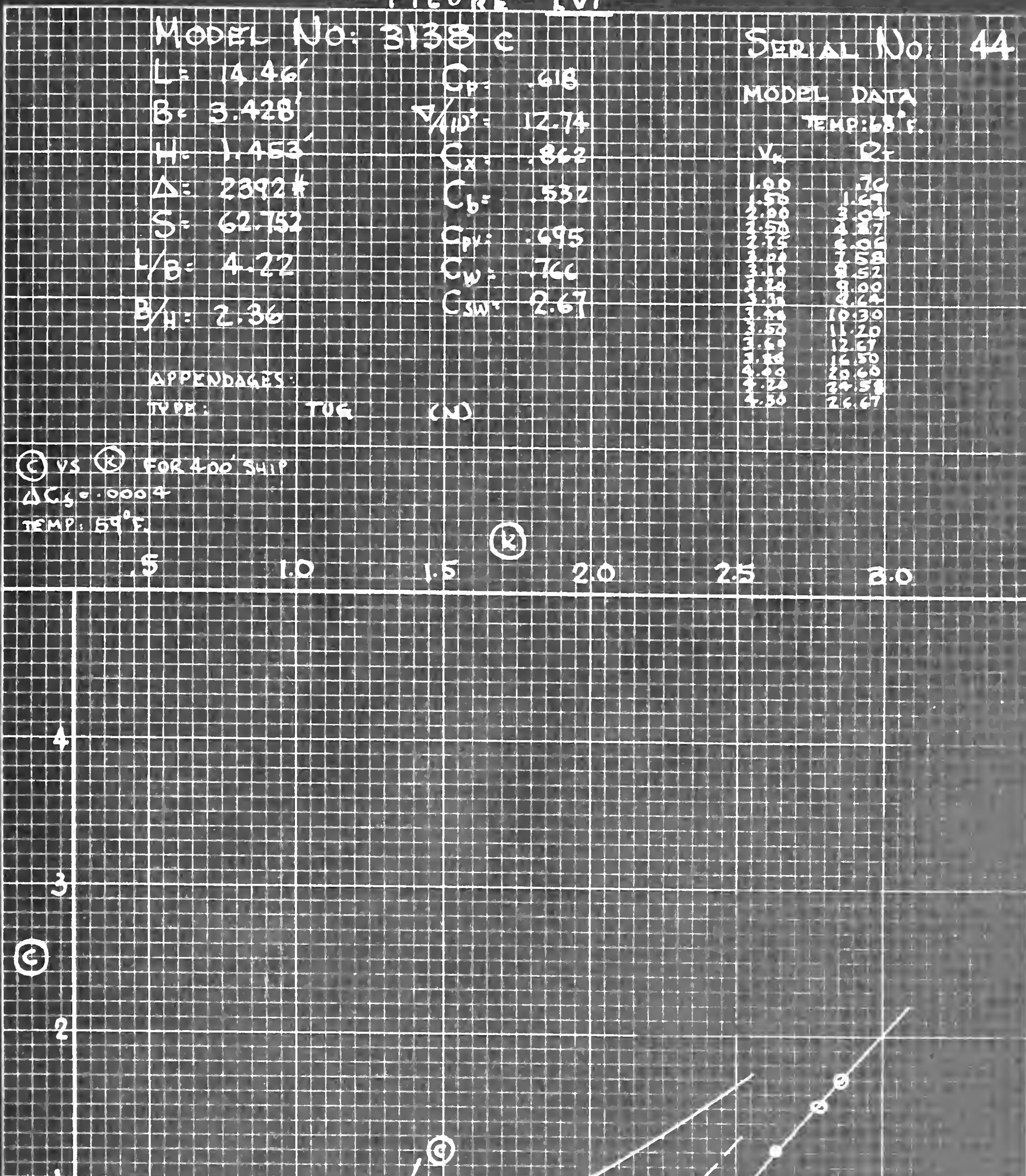

MODEL NO: 4094
SERIAL NO: 43
L = 11.11′
B = 3.042′
H = 1.233′
Δ = 1382 #
S = 45.071 □
L/B = 3.65
B/H = 2.465
C_p = .592
∇/(.1L)³ = 16.18
C_x = .898
C_b = .531
C_{pv} = .713
C_w = .745
C_{sw} = 2.87
MODEL DATA
TEMP: 65°F
V_k R_T
1.00 .99
1.50 1.41
1.75 1.95
2.00 2.59
2.25 3.33
2.50 4.14
2.75 5.14
3.00 6.41
3.25 8.12
3.50 9.95
3.75 12.00
4.00 16.03
4.10 18.79
4.20 22.30
4.30 27.05
APPENDAGES: RUDDER (SAND STRIP TURB)
TYPE: TUG (USAB)
Ⓒ vs Ⓚ FOR 400′ SHIP
ΔC_f = .0004
TEMP: 59°F
Ⓚ
.5 1.0 1.5 2.0 2.5 3.0
Ⓒ
1 2 3 4
C_n $\times 10^3$
2 4 6 8 10 12
Ⓒ
PREDICTED C_n
C_n
.10 .15 .20 .25 .30 .35
$V/\sqrt{gL}$

FIGURE LVI


MODEL NO: 3138 C
SERIAL NO: 44
L = 14.46'
B = 3.428'
H = 1.453'
Δ = 2392#
S = 62.752
L/B = 4.22
B/H = 2.36
Cp = .618
∇/(L/10)³ = 12.74
Cx = .862
Cb = .532
Cpv = .695
Cw = .766
Csw = 2.67
APPENDAGES:
TYPE: TUG (N)
MODEL DATA
TEMP: 68° F.
Vk Rt
1.00 .76
1.50 1.69
2.00 3.04
2.50 4.87
2.75 6.06
3.00 7.58
3.10 8.52
3.20 9.00
3.30 9.64
3.40 10.30
3.50 11.20
3.60 12.67
3.80 16.50
4.00 20.60
4.20 24.58
4.50 26.67
© VS ® FOR 400' SHIP
ΔCf = .0004
TEMP: 59° F.
®
.5 1.0 1.5 2.0 2.5 3.0
©
1 2 3 4
2 4 6 8 10 12
Cr x10³
PREDICTED Cr
Cr
.10 .15 .20 .25 .30 .35
V/√gL

Appendix (F)

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